In discussions between EPA and the water utility industry, concerns have been expressed about the difficulties in collecting samples and the requisite skills that may be required. EPA emphasizes that the skills required to sample for radon are the same as those required to sample for other currently regulated drinking water contaminants, namely volatile organic contaminants. In addition, the 1992 EPA collaborative study mentioned earlier evaluated four sample collection techniques and found them all capable of providing equivalent results. Supplementing this study, EPA has reviewed a sampling protocol for radon in water developed by the Department of Health Services Division of Drinking Water and Environmental Management (CA DHS 1998). This protocol employs one of the four techniques evaluated by EPA, the immersion technique.

Using the immersion technique, the well is purged for 15 minutes by running the sampling tap, to ensure that a representative sample is collected. After the purging period, a length of flexible plastic tubing is attached to the spigot, tap, or other connection, and the free end of the tubing is placed at the bottom of a small bucket. The water is allowed to fill the bucket, slowly, until the bucket overflows. The bucket is emptied and refilled at least once.

Once the bucket has refilled, a glass sample container of an appropriate size is opened and slowly immersed into the bucket in an upright position. Once the bottle has been placed on the bottom of the bucket, the tubing is placed into the bottle to ensure that the bottle is flushed with fresh water. After the bottle has been flushed, the tubing is removed while the bottle is resting on the bottom of the bucket. The cap is placed back on the bottle while the bottle is still submerged, and the bottle is tightly sealed. As noted in the California protocol cited earlier, the choice of the sample container is dependent on the laboratory that will perform the analysis, and will be a function of the liquid scintillation counter that is employed. If bottles are supplied by the laboratory, there is no question of what container to employ.

Once the sealed sample bottle is removed from the bucket, it is inverted and checked for bubbles that would indicate headspace. If there are no visible air bubbles, the outside of the sealed bottle is wiped dry and cap is sealed in place with electrical tape, wrapped clockwise. After the sample bottle is sealed, a second (duplicate) sample is collected in the same fashion from the same bucket. The date and time of the sample collection is recorded for each sample.

As can be surmised from the description, the sample collection procedures are not particularly labor intensive. Most of the time is spent allowing the water to overflow the bucket. Likewise, there are no significant manual skills required.

(e) Skill Considerations for Laboratory Personnel. While neither of these techniques is difficult relative to standard drinking water methods, a discussion of the skills required to employ the methods is appropriate. Given the long history of successful use of the liquid scintillation counting technique (it has been used in medical laboratories and environmental research laboratories for well over 30 years), EPA feels confident that State drinking water laboratories will be able to adequately use these methods. The skills required are primarily the ability to transfer and mix aliquots of the sample to a sealed container for further analysis. The counting process is highly automated and the equipment runs unattended for days, if needed.

The de-emanation process requires somewhat more manual skill. As noted in the 1991 proposed rule, EPA expects that this technique would require greater efforts be made to train technicians than for the liquid scintillation technique. The technique requires that the counting cell be evacuated to about 10 mTorr pressure and then a series of stopcocks or valves are manipulated to transfer the radon that is purged from the sample into the counting cell. Potential problems with the analysis, such as a high background level of radon that can develop over the course of the day, or aspirating water into the counting cell, can be minimized by a well-trained analyst. However, as EPA concluded in 1991, the Lucas cell technique is not expected to form the sole basis of a compliance monitoring program for radon in drinking water.

(f) Cost of Performing Analyses. The actual costs of performing analysis may vary with laboratory, analytical technique selected, the total number of samples analyzed by a lab, and by other factors. Based upon information collected in 1991, the average sample cost for radon in water was estimated to be $50 per sample. EPA recently updated this cost estimate to $57 per sample (USEPA 1999b) by conducting a similar survey of drinking water laboratories. The data from the 1991 and 1998 surveys and the descriptive statistics are summarized in Table VIII.B.2. There was no clear correlation between the estimated price and the method cited by the laboratory. The 1998 range of prices brackets those collected by EPA in 1991. It is expected that the ''market forces'' generated by a radon regulation will tend to lower per sample costs, especially in light of the fact the LSC is very amenable to automation, with feed capacities of more than 50 samples/load possible. However, as will be discussed later, there may be short-term laboratory capacity issues that resist a lowering of per sample prices.

TABLE VIII.B.2. RADON SAMPLE COST ESTIMATE

Arbitrary lab No.	Cost estimate	Year data collected	Descriptive statistics for 1991
1	$30	1991	Mean, $49.80; Median, $47.00; Std. Dev., $18.80; Range, $45; Minimum, $30; Maximum, $75.
2	44	1991	
3	50	1991	
4	75	1998	
			Descriptive Statistics for 1998 Data
5	75	1998	Mean, $56.88; Median, $52.50; Std. Dev., $15.80; Range, $35; Minimum, $40; Maximum, $75.
6	50	1998	
7	40	1998	
8	75	1998	
9	45	1998	
10	55	1998	
11	75	1998	
12	40	1998	

These cost data are preliminary and may be different in practice for the following reasons: (a) As the number of experienced laboratories increases, the costs can be expected to decrease; (b) analytical costs are determined, to some extent, by the quality control efforts and quality assurance programs adhered to by the analytical laboratory; (c) per-sample costs are influenced by the number of samples analyzed per unit time. EPA solicits comments on its cost estimates from laboratories experienced in performing these analyses.

(g) Method Detection Limits and Practical Quantitation Levels. Method detection limits (MDLs) and practical quantitation levels (PQLs) are two performance measures used by EPA to estimate the limits of performance of analytic chemistry methods for measuring contaminants in drinking water. An MDL is the lowest level of a contaminant that can be measured by a specific method under ideal research conditions. EPA usually defines the MDL as the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the true value is greater than zero. The term MDL is used interchangeably with minimum detectable activity (MDA) in radionuclide analysis, which is defined as that amount of activity which in the same counting time, gives a count which is different from the background count by three times the standard deviation of the background count. A PQL is the level at which a contaminant can be ascertained with specified methods on a routine basis (such as compliance monitoring) by accredited laboratories, within specified precision and accuracy limits.

The feasibility of implementing an MCL at a particular level is in part determined by the ability of analytical methods to ascertain contaminant levels with sufficient precision and accuracy at or near the MCL. The proposed methods demonstrate good reproducibility and accuracy at radon concentrations in the range of 150–300 pCi/L (half of the proposed MCL up to the proposed MCL), as demonstrated in the results from inter-laboratory studies. In inter-laboratory studies (or Performance Evaluation studies), prepared samples of known concentration are distributed for analysis to participating labs, which have no information on the concentrations of the samples. The results of the analyses by the participants are compared with the known value and with each other to estimate the precision and accuracy of both the methods used and the lab's proficiency in using the method. Table VIII.B.3 summarizes the statistical results of these inter-laboratory studies for the proposed methods.

In the 1991 proposed rule, EPA proposed using both the MDL and PQL as measures of performance for radon analytical methods. EPA also proposed acceptance limits based on the PQLs that were derived from these performance evaluation studies. The use of acceptance limits was confusing to commenters for various reasons. The important issue is the observation that true analytical method performance is related to within-laboratory conditions (including counting times in the case of radiochemicals) and that acceptance limits are based on multi-laboratory Performance Evaluation studies. For non-radiochemical contaminants this issue is less troublesome because their PQLs tend to be ''fixed'' since the MDLs to which they are related reflect optimized conditions for standard laboratory equipment, whereas for radiochemical contaminants, counting times can always be increased to increase the sensitivity and hence lower the appropriate acceptance limits. While the fifty minute counting time in Standard Method 7500-Rn reflects a balanced trade-off between time of analysis (and hence the cost of analysis) and sensitivity, it can obviously be adjusted as needed to adjust sensitivity. For this reason, commenters objected to the use of acceptance limits (and, relatedly, PQLs) for radiochemical contaminants.

EPA agrees that these comments have merit and has decided to seek comment on two proposals regarding the use of acceptance limits and PQLs for radon. The first proposal, and the preferred option, is to not use acceptance limits or PQL for radon, and to adopt the detection limit as the measure of sensitivity, as done in the 1976 Radionuclides rule. The existing definition of the detection limit takes into account the influence of the various factors (efficiency, volume, recovery yield, background, counting time) that typically vary from sample to sample. Thus, the detection limit applies to the circumstances specific to the analysis of an individual sample and not to an idealized set of measurement parameters, as with acceptance limits and PQLs. The proposed detection limit is 12 +/− 12 pCi/L, which is based on the detection limit described in SM 7500-Rn (50 minute counting time, 6 cpm background, 2.7 cpm/dpm efficiency, and under the energy window optimization procedure as described in the method). This detection limit should be applicable to all three approved methods.

One of the reasons for setting a sensitivity standard is to ensure that laboratories will perform acceptably well on a routine basis at contaminant levels near the MCL. Internal quality control/quality assurance procedures are of paramount importance. In addition, Proficiency Tests are administered by laboratory certifying authorities to ensure that laboratory performance is acceptable. Currently, the system for administering proficiency tests and certifying laboratories is in a state of transition. Up to the recent past, all primacy entities evaluated laboratory performance based on EPA's Performance Evaluation (PE) studies program, the National Exposure Research Laboratory (NERL–LV) Performance Evaluation (PE) Studies program for radioactivity in drinking water. Currently, the Proficiency Testing (PT) program for radionuclides is being privatized, *i.e.*, operated by an independent third party provider accredited by the National Institute of Standards and Technology (NIST). A lack of uniformity in state PT requirements may limit laboratory availability for a given public water system to laboratories that use PT samples approved by the state. It should be noted that this issue is general and is not specific to the proposed radon regulation. Efforts to encourage uniformity in state PT requirements are described in more detail in the laboratory capacity section.

Under the alternative of using the MDL as the measure of sensitivity, standard statistical procedures would be used to ensure that a laboratory has analyzed PT samples acceptably. Since the national PT program will still be overseen by EPA, the exact procedures for determining acceptable performance will be developed by EPA and NIST as the PT program develops. The respective roles of EPA and NIST in the PT program and discussed further in the Laboratory Approval and Certification section.

The second proposal is to use the concepts of the acceptance limit and PQL for radon. Using the standard relationship that PQLs are equal to 5 to 10 times the MDL yields a PQL for radon in the range of 60 to 240 pCi/L. EPA is proposing a PQL of 100 pCi/L and is seeking comment on this value. The proposed acceptance limit for a single sample is ±5 %. The proposed acceptance limits for triplicate analyses at the 95th and 99th percent confidence intervals are ±6 % and ±9 %, respectively. All of these acceptance limits are based on the inter-laboratory studies used for the precision and accuracy results reported in Table

VIII.B.3. EPA seeks comments on the relative merits between the first option (the preferred option) of using only an MDL as the measure of sensitivity and the second option of using a PQL with prescribed acceptance limits.

TABLE VIII.B.3.—INTER-LABORATORY PERFORMANCE DATA FOR PROPOSED RADON ANALYTICAL METHODS [1]

Method	Sample Conc. pCi/L	Accuracy %	Repeat-ability pCi/L	Reproduc-ibility pCi/Ls	Bias %
SM 7500-Rn	111	101–102	9	12	0.7–2.3
SM 7500-Rn	153	102–103	10	16–18	2.3–3.4
De-Emanation	111	114	16	23	14.5
De-Emanation	153	114	17	28	13.7
ASTM D5072–92	1,622	97	2,217	3,541	−2.6
ASTM D5072–92	16,324	95	14,950	44,400	−4.7
ASTM D5072–92	66,324	94	49,190	210,350	−6.0

Notes: (1) All results are reported in methods citations found in Table VIII.B.1.

(h) Accuracy and Precision of the Proposed Methods. While SM 7500-Rn has the best over-all results in precision and accuracy, the de-emanation method also shows acceptable performance. The ASTM method shows similar accuracy and bias, but much larger errors in repeatability (operator precision) and reproducibility (between-lab precision). Given this inferior demonstration of precision and the higher concentrations used in the intra-laboratory studies, it may be argued that this method should not be proposed as a drinking water method. However, EPA maintains that the method is similar enough in substance to SM 7500-Rn that it may serve as an alternate method if the laboratories use the appropriate quality control measures, *i.e.,* ensure that the relative percent difference between results on duplicate samples is within the counting uncertainty 95% confidence interval, where at least 10% of daily samples are duplicates. This procedure is described in the 4th edition of the Manual for the Certification of Laboratories Analyzing Drinking Water, Criteria and Procedures Quality Assurance (EPA 1997). EPA requests comment on including ASTM D5072–92 as an alternate test method.

C. Laboratory Approval and Certification

1. Background

The ultimate effectiveness of the proposed regulations depends upon the ability of laboratories to reliably analyze contaminants at relatively low levels. The Drinking Water Laboratory Certification Program is intended to ensure that approved drinking water laboratories analyze regulated drinking water contaminants within acceptable limits of performance. The Certification Program is managed through a cooperative effort between EPA's Office of Ground Water and Drinking Water and its Office of Research and Development. The program stipulates that laboratories analyzing drinking water compliance samples must be certified by U.S. EPA or the State. The program also requires that certified laboratories must analyze PT samples, use approved methods, and States must also require periodic on-site audits.

External checks of performance to evaluate a laboratory's ability to analyze samples for regulated contaminants within specific limits is one of the means of judging lab performance and determining whether to grant certification. Under a PT program, laboratories must successfully analyze PT samples (contaminant concentrations are unknown to the laboratory being reviewed) that are prepared by an organization that is approved by the primacy entity. Successful annual participation in the PT program is prerequisite for a laboratory to achieve certification and to remain certified for analyzing drinking water compliance samples. Achieving acceptable performance in these studies of known test samples provides some indication that the laboratory is following proper practices. Unacceptable performance may be indicative of problems that could affect the reliability of the compliance monitoring data.

EPA's previous PE sample program and the approaches to determine laboratory performance requirements are discussed in 63 FR 47097 (September 3, 1998, "1998 methods update"). In that notice, EPA amended the regulations to adopt the universal requirement for laboratories to successfully analyze a PE sample at least once each year, addressing the fact that the Agency has not specified PE test frequency requirements in its current drinking water regulations. Though not specified in the methods update regulation, PE samples may be provided by EPA, the State, or by a third party with the approval of the State or EPA. Under the developing PT program, NIST has accredited a list of PT sample providers, including a radionuclides PT samples which will apply to radon.

In addition, guidance on minimum quality assurance requirements, conditions of laboratory inspections, and other elements of laboratory certification requirements for laboratories conducting compliance monitoring measurements are detailed in the 4th edition of the Manual for the Certification of Laboratories Analyzing Drinking Water, Criteria and Procedures Quality Assurance (EPA 1997), which can be downloaded via the internet at "http://www.epa.gov/OGWDW/labindex.html".

2. Laboratory Capacity—Practical Availability of the Methods

In order to determine the practical availability of the methods, EPA considered three major factors. First, the availability of the major instrumentation was reviewed. Secondly, several laboratories performing drinking water analyses were contacted to determine their potential capabilities to perform radon analyses. Lastly, EPA has reviewed the current status of the privatized Performance Evaluation studies program and the on-going measure to implement a uniform program, highlighting the potential impacts on short-term and long-term laboratory capacity for radon.

3. Laboratory Capacity: Instrumentation

Regarding instrumentation availability, the major instrumentation required for LSC is the liquid scintillation counter. Automated counters capable of what that method terms "automatic spectral analysis" are available from at least a dozen suppliers. The de-emanation Lucas cell apparatus is the same apparatus that has been used for radium analyses for many years. In light of the wide availability and the long history of accessibility of the proper instrumentation, EPA believes that instrument availability should not be an issue for radon analytical methods.

4. Laboratory Capacity: Survey of Potential Laboratories

In order to evaluate the availability of laboratory capacity to perform radon analyses, EPA contacted the drinking water certification authorities in the States of California, Maryland, and Pennsylvania. These states were chosen based both on estimated radon occurrence and the overall status of the programs. Ultimately, EPA collected information on the availability and relative costs of radon analyses for drinking water from a total of nine commercial laboratories.

Eight of the nine laboratories that were contacted do perform radon analyses. All the laboratories were certified in one or more states to perform radiochemical analyses. When asked what specific methods were used, the laboratories responded with either the technique (liquid scintillation counting) or a specific method citation. EPA Method 913 (which later was revised to become SM 7500-Rn) was cited by two of the laboratories. EPA Method ''EERF Appendix B'' was cited by another laboratory. The remaining laboratories indicated that they performed liquid scintillation analyses and could accommodate requests for methods employing that technique.

When asked about capacity, the laboratories indicated that they each perform between 100 and 12,000 analyses per year. The latter figure came from a laboratory that is currently involved in a large ground water monitoring project in the western United States. The next largest estimate was 300 samples per year. However, EPA expects that like any other type of environmental analysis, given a regulatory ''driver'' to perform the analysis, and given the ability of LSC analysis to be automated, the laboratory capacity will develop in a timely manner.

EPA's 1992 Annual Report on Radiation Research and Methods Validation reports the results of a collaborative study on radon analysis (EPA 1993) and is another useful source of information regarding potential radon laboratory capacity. This study employed 51 laboratories with the capability to perform liquid scintillation analyses. This suggests that at that time there already existed a substantial capacity for these analyses.

Further, the liquid scintillation apparatus is used for other radiochemical analyses, including tritium. Information from EPA regarding the performance evaluation program for tritium analyses suggests that there are approximately 100–200 laboratories with the necessary equipment. Much of the capacity for tritium analyses could also be used for radon (EPA 1997). As of September 1997, 136 of 171 participating laboratories achieved acceptable results for tritium. While the total number of participants and the number achieving acceptable results vary between studies, the data indicate that there is a substantial capability for liquid scintillation analysis nationwide.

5. Laboratory Capacity: Laboratory Certification and Performance Evaluation Studies

The availability of laboratories is also dependent on laboratory certification efforts in the individual states with regulatory authority for their drinking water programs. Until June of 1999, a major component of many of these certification programs was their continued participation in the current EPA Water Supply WS performance evaluation (PE) program, which included radiochemistry PE studies. Due to resource limitations, EPA has recently privatized EPA's PE programs, including the Water Supply studies. EPA has addressed this topic in public stakeholders meetings and in some recent publications, including **Federal Register** notices and its June 1997 ''Labcert Bulletin'', which can be downloaded from the Internet at ''http://www.epa.gov/OGWDW/labcert3.html''. The decision to privatize the PE studies programs was announced in the **Federal Register** on June 12, 1997 (62 FR 32112). This notice indicated that in the future the National Institute of Standards and Technology (NIST) would develop standards for private sector PT sample providers and would evaluate and accredit these providers, while the actual development and manufacture of PT samples would fall to the private sector. Further information regarding the respective roles of EPA and NIST in the privatized PT program can be downloaded from NIST's homepage at ''http://ts.nist.gov/ts/htdocs/210/210.htm''. EPA believes that this program will ensure the continued viability of the existing PT programs, while maintaining government oversight.

This externalized proficiency testing program is in the process of becoming operational. Under the externalized PT program:

- EPA issues standards for the operation of the program,
- NIST administers a program to accredit PT sample providers,
- Non-EPA PT sample providers develop and manufacture PT sample materials and conduct PT studies,
- Environmental laboratories purchase PT samples directly from PT Sample Providers (approved by NIST or the State), and
- Certifying authorities certify environmental laboratories performing sample analyses in support of the various water programs administered by the States and EPA under the Safe Drinking Water Act.

NIST is in the process of approving a provider for PT samples for radionuclides, including radon. States also have the option of approving their own PT sample providers. At this time, it is difficult to speculate to what degree this externalization of the PT program will affect short-term and long-term laboratory capacity for radon. EPA recognizes that initial implementation problems may arise because of the potential for near-term limited availability of radon PT samples. EPA also recognizes that insufficient laboratory capacity may lead to a short-term increase in analytical costs. In the absence of definitive information regarding the future PT program, EPA solicits public comment on this matter.

6. Efforts To Ensure a Uniform Proficiency Testing Program: NELAC

The National Environmental Laboratory Accreditation Conference (NELAC) is also evaluating the issues surrounding privatization of the SDWA PT program through its proficiency testing committee. NELAC serves as a voluntary national standards-setting body for environmental laboratory accreditation, and includes members from both state and Federal regulatory and non-regulatory programs having environmental laboratory oversight, certification, or accreditation functions. One of the goals for the re-designed SDWA PT program is to be consistent with NELAC's recommendations.

The members of NELAC meet bi-annually to develop consensus standards through its committee structure. These consensus standards are adopted by participants for use in their own programs in pursuit of a uniform national laboratory accreditation program in which environmental testing laboratories will be able to receive one annual accreditation that is accepted nationwide. As part of its accreditation program, NELAC is developing standards for a proficiency testing program that addresses all fields of testing, including drinking water. Recent meetings of the Proficiency Testing Committee of NELAC have reviewed several important issues, including State selection of PT sample providers and reciprocity between States.

These issues are described in more detail elsewhere (NELAC 1999a). The NELAC Proficiency Testing Committee is currently drafting requirements for radiochemical proficiency testing under SDWA. The June 15, 1999 draft (NELAC 1999b) of its radiochemical proficiency testing requirements describes radiochemical PT sample designs, acceptance limits, and other information.

The intent of the NELAC standards setting process is to ensure that the needs of EPA and state regulatory programs are satisfied in the context of a uniform national laboratory accreditation program. EPA recognizes that cooperating with NELAC is an important part of the re-design of the Proficiency Testing (PT) program for drinking water, since NELAC provides a means for states, environmental testing laboratories, and PT study providers to have direct input into the process. It is hoped that this mutual effort will minimize the potential disruption in the process of moving from the old EPA PE program towards the new privatized PT program. EPA shares NELAC's goal of encouraging uniformity in standards between primacy States regarding laboratory proficiency testing and accreditation.

7. Laboratory Capacity: Holding Time

The short holding time for radon, 4 days in Method 7500-Rn, presents concerns relative to the practical availability of laboratory capacity as well. The 4-day holding time was also the focus of a number of comments that EPA received in response to the 1991 proposed rule. Many commenters were concerned that if a local laboratory is not available, the only alternative will be to send the samples by overnight delivery to a laboratory elsewhere. However, this situation is not unique to the analysis of radon. As evidenced during the data gathering pursuant to the Disinfection By-Products Information Collection Rule (DBP ICR), several large commercial laboratories already account for a sizable share of the market for SDWA analyses for non-radon parameters, including organics, for which the holding times are often 7 days. Given that a day would be required for shipping the samples, only three days would remain for the laboratory to perform the radon analysis (the day on which the sample is collected being ''day zero''). Some commenters argued that for a large commercial laboratory serving the water utilities, this short holding time will make it difficult if not impossible to perform the necessary analyses within the holding time. However, through common sense scheduling efforts between the utility and the laboratory, such as not collecting samples on Thursdays and Fridays, the holding time issue should be able to be accommodated in light of the ability of the LSC method to be highly automated.

D. Performance-Based Measurement System (PBMS)

On October 6, 1997, EPA published a Notice of the Agency's intent to implement a Performance Based Measurement System (PBMS) in all of its programs to the extent feasible (62 FR 52098). EPA is currently determining how to adopt PBMS in its drinking water program, but has not yet made final decisions. When PBMS is adopted in the drinking water program, its intended purpose will be to increase flexibility in laboratories in selecting suitable analytical methods for compliance monitoring, significantly reducing the need for prior EPA approval of drinking water analytical methods. Under PBMS, EPA will modify the regulations that require exclusive use of Agency-approved methods for compliance monitoring of regulated contaminants in drinking water regulatory programs. EPA will probably specify ''performance standards'' for methods, which the Agency would derive from the existing approved methods and supporting documentation. A laboratory would then be free to use any method or method variant for compliance monitoring that performed acceptably according to these criteria. EPA is currently evaluating which relevant performance characteristics should be specified to ensure adequate data quality for drinking water compliance purposes. After PBMS is implemented, EPA may continue to approve and publish compliance methods for laboratories that choose not to use PBMS. After EPA makes final determinations to implement PBMS in programs under the Safe Drinking Water Act, EPA would then provide specific instruction on the specified performance criteria and how these criteria would be used by laboratories for radon compliance monitoring.

E. Proposed Monitoring and Compliance Requirements for Radon

1. Background

The monitoring regulation for radon proposed in 1991 by EPA required that groundwater systems monitor for radon at each entry point to the distribution system quarterly for one year initially. Monitoring could be reduced to one sample annually per entry point to the distribution system if the average of all first quarterly samples was below the MCL. States could allow systems to reduce monitoring to once every three years if the system demonstrated that results of all previous samples collected were below the MCL. The proposal also allowed States to grant waivers to groundwater systems to reduce the frequency of monitoring, up to once every 9 years, if States determined that radon levels in drinking water were consistently and reliably below the MCL. Comments made in response to the proposed monitoring requirements for radon were mainly concerned that the proposed monitoring requirements including number of samples and the frequency of monitoring did not adequately take into account the effect of seasonal variations in radon levels on determining compliance. Other commenters felt that sampling at the entry point of the distribution system was not representative of exposure to radon, and they suggested that sampling for radon should be done at the point of use.

Since the 1991 proposal EPA has obtained additional information from States, the waterworks industry and academia on the occurrence of radon, including data on the temporal variability of radon. Utilizing this additional data, the Agency performed extensive statistical analyses to predict how temporal, analytical variations and variations between individual wells may affect exposure to radon. The results of these analyses are described in detail in the report ''Methods, Occurrence and Monitoring Document for Radon'' in the docket for this rule (USEPA 1999g). As a result of the new information available, EPA was able to refine the requirements for monitoring and address the concerns expressed by the commenters on the 1991 proposal.

The proposed monitoring requirements for radon are consistent with the monitoring requirements for regulated drinking water contaminants, as described in the Standardized Monitoring Framework (SMF) promulgated by EPA under the Phase II Rule of the National Primary Drinking Water Regulations (NPDWR) and revised under Phases IIB and V. The goal of the SMF is to streamline the drinking water monitoring requirements by standardizing them within contaminant groups and by synchronizing monitoring schedules across contaminant groups. A summary of monitoring requirements in this proposal, the SMF and the 1991 proposal are provided in Table VIII.E.1.

TABLE VIII.E.1.—COMPARISON OF MONITORING REQUIREMENTS

Monitoring requirements for radon		
1991 Proposal	1999 Proposal—MCL/AMCL	SMF for IOCs in groundwater
Initial Monitoring Requirements		
Four consecutive quarters of monitoring at each entry point for one year. Initial monitoring was proposed to have been completed by January 1, 1999.	Four consecutive quarters of monitoring at each entry point. Initial monitoring must begin by three years from date of publication of the final rule in FEDERAL REGISTER of 4.5 years from date of publication of the final rule in FEDERAL REGISTER (depending on effective date applicable to the State).	Four consecutive quarters of monitoring at each entry point for sampling points initially exceeding MCL.
Routine Monitoring Requirements		
One sample annually if average from four consecutive quarterly samples taken initially is less than MCL.	One sample annually if average from four consecutive quarterly samples is less than MCL/AMCL, and at the discretion of State.	One sample at each sample point during the initial 3 year compliance period for groundwater systems for sampling points below MCL.
1991 Proposal	1999 Proposal—MCL	SMF for IOCs in Groundwater
Reduced Monitoring Requirements		
State may allow groundwater systems to reduce the frequency of monitoring to once every three years provided that they have monitored quarterly in the initial year and completed annual testing in the second and third year of the first compliance period. Groundwater systems must demonstrate that all previous analytical samples were less than the MCL.	State may allow CWS using groundwater to reduce monitoring frequency to:. Once every three years if average from four consecutive quarterly samples is less than ½ the MCL/AMCL, provided no samples exceed the MCL/AMCL. and if the system is determined by State to be ''reliably and consistently below MCL/AMCL ''.	State may allow groundwater systems to reduce monitoring frequency to: Once every three years if samples subsequently detects less than MCL and determined by State to be ''reliably and consistently below MCL.''
Monitoring Requirements for Radon		
1991 Proposal	1999 Proposal—MCL/AMCL	SMF for IOCs in Groundwater
Increased Monitoring Requirements		
Systems monitoring annually or once per three year compliance period exceed the radon MCL in a single sample would be required to revert to quarterly monitoring until the average of 4 consecutive samples is less than the MCL. Groundwater systems with unconnected wells would be required to conduct increased monitoring only at those wells exceeding the MCL. The State may require more frequent monitoring than specified. Systems may apply to the State to conduct more frequent monitoring than the minimum monitoring frequencies specified.	Systems monitoring annually would be required to increase monitoring if the MCL/AMCL for radon is exceeded in a single sample, the system would be required to revert to quarterly monitoring until the average of 4 consecutive samples is less than the MCL/AMCL. Systems monitoring once every three years would be required to monitor annually if the radon level is less than MCL/AMCL but above ½ MCL/AMCL in a single sample. Systems may revert to monitoring once per three years if the average of the initial and three consecutive annual samples is lees than ½ MCL/AMCL. CWS using groundwater with un-connected wells would be required to conduct increased monitoring only at those well which are affected.	If the MCL is exceeded in a single sample, the system required to begin sampling quarterly until State determines that it is ''reliably and consistently'' below MCL.

TABLE VIII.E.1.—COMPARISON OF MONITORING REQUIREMENTS—Continued

Monitoring requirements for radon		
1991 Proposal	1999 Proposal—MCL/AMCL	SMF for IOCs in groundwater
Monitoring Requirements for Radon		
1991 Proposal	1999 Proposal—MCL	SMF for IOCs in Groundwater
Confirmation Samples		
Where the results of sampling indicate an exceedence of the maximum contaminant level, the State may require that one additional sample be collected as soon as possible after the initial sample was taken [but not to exceed two weeks] at the same sampling point. The results of the of the initial sample and the confirmation sample shall be averaged and the resulting average shall be used to determine compliance.	Systems may collect confirmation samples as specified by the State. The average of the initial sample and any confirmation samples will be used to determine compliance.	Where the results sampling indicate an exceedence of the maximum contaminant level, the State may require that one additional sample be collected as soon as possible after the initial sample was taken [but not to exceed two weeks] at the same sampling point. The results of the initial sample and the confirmation sample shall be averaged and the resulting average shall be used to determine compliance.
Grandfathering of Data		
If monitoring data collected after January 1, 1985 are generally consistent with the requirements specified in the regulation, than the State may allow the systems to use those data to satisfy the monitoring requirements for the initial compliance period.	If monitoring data collected after proposal of the rule are consistent with the requirements specified in the regulation, then the State may allow the systems to use those data to satisfy the monitoring requirements for the initial compliance period.	States may allow previous sampling data to satisfy the initial sampling requirements provided the data were collected after January 1, 1990.
Monitoring Requirements for Radon		
1991 Proposal	1999 Proposal—MCL	SMF for IOCs in Groundwater
Waivers		
State may grant waiver to groundwater systems to reduce the frequency of monitoring, up to nine years. If State determines that radon levels in drinking water are ''reliably and consistently'' below the MCL.	The State may grant a monitoring waiver to systems to reduce the frequency of monitoring to up to one sample every nine years based on previous analytical results, geological characteristics of source water aquifer and if a State determines that radon levels in drinking water are ''reliably and consistently'' below the MCL/AMCL. Analytical results of all previous samples taken must be below ½ the MCL/AMCL.	The State may grant waiver to groundwater systems after conducting vulnerability assessment to reduce the frequency of monitoring, up to nine years, if State determines that radon levels in drinking water are ''reliably and consistently'' below the MCL. System must have three previous samples. Analytical results of all previous samples taken must be below MCL.

In developing the proposed compliance monitoring requirements for radon, EPA considered:

(1) The likely source of contamination in drinking water;

(2) The differences between ground water and surface water systems;

(3) The collection of samples which are representative of consumer exposure;

(4) Sample collection and analytical methods;

(5) The use of appropriate historical data to identify vulnerable systems and to specify monitoring requirements for individual systems;

(6) The analytical, temporal and intra-system variance of radon levels;

(7) The use of appropriate historical data and statistical analysis to establish reduced monitoring requirements for individual systems; and

(8) The need to provide flexibility to the States to tailor monitoring requirements to site-specific conditions by allowing them to:

—Grant waivers to systems to reduce monitoring frequency, provided certain conditions are met.
—Require confirmation samples for any sample exceeding the MCL/AMCL.
—Allow the use of previous sampling data to satisfy initial sampling requirements.
—Increase monitoring frequency.
—Decrease monitoring frequency.

2. Monitoring for Surface Water Systems

CWSs relying exclusively on surface water as their water source will not be required to sample for radon. Systems that rely in part on ground water would be considered groundwater systems for purposes of radon monitoring. Systems that use ground water to supplement surface water during low-flow periods will be required to monitor for radon. Ground water under the influence of surface water would be considered ground water for this regulation.

3. Sampling, Monitoring Schedule and Initial Compliance for CWS Using Groundwater

EPA is retaining the quarterly monitoring requirement for radon as proposed initially in the 1991 proposal to account for variations such as sampling, analytical and temporal variability in radon levels. Results of analysis of data obtained since 1991, estimating contributions of individual sources of variability to overall variance in the radon data sets evaluated, indicated that sampling and analytical variance contributes less than 1 percent to the overall variance. Temporal variability within single wells accounts for between 13 and 18 percent of the variance in the data sets evaluated, and a similar proportion (12–17 percent) accounts for variation in radon levels among wells within systems. (USEPA 1999g)

The Agency performed additional analyses to determine whether the requirement of initial quarterly monitoring for radon was adequate to account for seasonal variations in radon levels and to identify non-compliance with the MCL/AMCL. Results of analysis based on radon levels modeled for radon distribution for ground water sources (USEPA 1999g) and systems (USEPA 1998a) in the U.S. show that the average of the first four quarterly samples provides a good indication of the probability that the long-term average radon level in a given source would exceed an MCL or AMCL. Tables VIII.E.2 and VIII.E.3 show the probability of the long-term average radon level exceeding the MCL and AMCL at various averages obtained from the first four quarterly samples from a source.

TABLE VIII.E.2.—THE RELATIONSHIP BETWEEN THE FIRST-YEAR AVERAGE RADON LEVEL AND THE PROBABILITY OF THE LONG-TERM RADON AVERAGE RADON LEVELS EXCEEDING THE MCL

If the average of the first four quarterly samples from a source is	Then the probability that the long-term average radon level in that source exceeds 300 pCi/L is
Less than 50 pCi/L	0 percent.
Between 50 and 100 pCi/L	0.5 percent.
Between 100 and 150 pCi/L.	0.4 percent.
Between 150 and 200 pCi/L.	7.2 percent.
Between 200 and 300 pCi/L.	26.8 percent.

TABLE VIII.E.3.—THE RELATIONSHIP BETWEEN THE FIRST-YEAR AVERAGE RADON LEVEL AND THE PROBABILITY OF THE LONG-TERM RADON AVERAGE RADON LEVELS EXCEEDING THE AMCL

If the average of the first four quarterly samples from a source is	Then the probability that the long-term average radon level in that source exceeds 4000 pCi/L is
Less than 2,000 pCi/L	Less than 0.1 percent.
Between 2,000 and 2,500 pCi/L.	9.9 percent.
Between 2,500 and 3,000 pCi/L.	15.1 percent.
Between 3,000 and 4,000 pCi/L.	32.9 percent.

The Agency proposes that systems relying wholly or in part on ground water will be required to initially sample quarterly for radon for one year at each well or entry point to the distribution system. All samples will be required to be of finished water, as it enters the distribution system after any treatment and storage. If the average of the four quarterly samples at each well is below the MCL/AMCL, monitoring may be reduced to once a year at State discretion. Systems may be required to continue monitoring quarterly in instances where the average of the quarterly samples at each well is below but close to the MCL/AMCL. The reason for this is that in such cases, there is a good chance for the long-term average radon level to exceed the MCL/AMCL.

Systems already on-line must begin initial monitoring for compliance with the MCL/AMCL by the compliance dates specified in the rule (*i.e.,* 3 years after the date of promulgation or 4.5 years after the date of promulgation). Monitoring requirements for new sources will be determined by the State. The compliance dates are discussed in detail in Section VII.E, Compliance Dates.

The Agency is retaining the requirement as proposed in 1991 to sample at the entry point to the distribution system. Sampling at the entry point allows the system to account for radon decay during storage and removal during the treatment process. The reason for not allowing sampling at the point of use is that this approach would not take into account higher exposure levels that may be encountered at locations upstream from the sampling site. In addition, sampling at the entry point will make it easier to identify and isolate possible contaminant sources within the system. The sample collection sites at each entry point to the distribution system and the monitoring schedule requiring sampling for four consecutive quarters proposed herein is consistent with the SMF. This approach streamlines monitoring since the same sampling points can be used for the collection of samples for other source-related contaminants.

EPA specifically requests comments on the following aspects of the proposed monitoring requirements:

- The appropriateness of the proposed initial monitoring period.
- The availability and capabilities of laboratories to analyze radon samples collected during the initial compliance period. The Agency recognizes that short-term implementation problems may arise to meet the initial monitoring deadline because of the potential limited availability of radon performance evaluation (PE) samples used to evaluate and certify laboratories.
- The appropriateness of the proposed number and frequency of samples required to monitor for radon.
- The designation of sampling locations at the entry point to the distribution system which is located after any treatment and storage. Comments are also solicited on the definition of sampling points that are representative of consumer exposure.
- Designating sampling locations and frequencies that permit simultaneous monitoring for all regulated contaminants, whenever possible and advantageous. The proposed sampling locations would be such that the same sampling locations could be used for the collection of samples for other source-related contaminants such as the volatile organic chemicals and inorganic chemicals, which would simplify sample collection efforts.

EPA also solicits comments on whether the monitoring requirements should include additional monitoring for radon as a source of consumer exposure from the distribution system. Results of investigations in Iowa indicate that in some instances, pipe scale deposited in the distribution system can be a source of exposure to radon. Community ground water systems could be required to collect an additional sample from the distribution system during the initial year of monitoring, at the same time the entry point sample is collected, and continue to collect samples from the distribution system annually if it is shown that exceedence of the MCL/AMCL is caused by the release of radon from deposited scale in the interior of the distribution system. Results obtained from distribution samples could provide information on the extent and frequency of occurrence of radon originating from distribution systems.

4. Increased/Decreased Monitoring Requirements

Initial compliance with the MCL/AMCL will be determined based on an average of four quarterly samples taken at individual sampling points in the initial year of monitoring. Systems with averages exceeding the MCL/AMCL at any sampling point will be deemed to be out of compliance. Systems in a non-MMM State exceeding the MCL will have the option to develop and implement a local MMM program in accordance with the timeframe discussed in Section VII.E, Compliance Dates without receiving a MCL violation.

Systems exceeding the MCL/AMCL will be required to monitor quarterly until the average of four consecutive samples is less than the MCL/AMCL. Systems will then be allowed to collect one sample annually if the average from four consecutive quarterly samples is less than the MCL/AMCL and if the State determines that the system is reliably and consistently below the MCL/AMCL.

Systems will be allowed to reduce monitoring frequency to once every three years (one sample per compliance period) per well or sampling point, if the average from four consecutive quarterly samples is less than ½ the MCL/AMCL and the State determines that the system is reliably and consistently below the MCL/AMCL. As shown in Tables VIII.E.2 and VIII.E.3, EPA believes that there is sufficient margin of safety to allow for this since there is a small probability that long term average radon levels will exceed the MCL/AMCL.

Systems monitoring annually that exceed the radon MCL/AMCL in a single sample will be required to revert to quarterly monitoring until the average of four consecutive samples is less than the MCL/AMCL. Community ground water systems with unconnected wells will be required to conduct increased monitoring only at those wells exceeding the MCL/AMCL. Compliance will be based on the average of the initial sample and three consecutive quarterly samples.

Systems monitoring once per compliance period or less frequently which exceed ½ the MCL/AMCL (but do not exceed the MCL/AMCL) in a single sample would be required to revert to annual monitoring. Systems may revert to monitoring once every three years if the average of the initial and three consecutive annual samples is less than ½ the MCL/AMCL. Community ground water systems with unconnected wells will be required to conduct increased monitoring only at those wells exceeding the MCL/AMCL.

States may grant a monitoring waiver reducing monitoring frequency to once every nine years (once per compliance cycle) provided the system demonstrates that it is unlikely that radon levels in drinking water will occur above the MCL/AMCL. In granting the monitoring waiver, the State must take into consideration factors such as the geological area where the water source is located, and previous analytical results which demonstrate that radon levels do not occur above the MCL/AMCL. The monitoring waiver will be granted for up to a nine year period. (Given that all previous samples are less than ½ the MCL/AMCL, then it is highly unlikely that the long-term average radon levels would exceed the MCL/AMCL.)

If the analytical results from any sampling point are found to exceed the MCL/AMCL (in the case of routine monitoring) or ½ the MCL/AMCL (in the case of reduced monitoring), the State may require the system to collect a confirmation sample(s). The results of the initial sample and the confirmation sample(s) shall be averaged and the resulting average shall be used to determine compliance.

EPA specifically requests comments on the following aspects of the proposed monitoring requirements :

- Allowing systems at State discretion, to reduce monitoring frequencies as long as the system demonstrates that its radon levels are maintained below the MCL/AMCL. For example, all community ground water systems would be required to collect one sample from each entry point to the distribution system (located after any treatment and storage) quarterly at first and annually after compliance is established. MCL/AMCL exceedence would trigger reverting to quarterly sampling until compliance with the MCL/AMCL is reestablished. Compliance is reestablished when the average of four consecutive quarterly samples is below the MCL/AMCL.
- Allowing States to reduce monitoring requirements to not less than once every three years if the average radon levels from four consecutive quarterly samples is less than ½ the MCL/AMCL, and the State determines that the radon levels in the drinking water are reliably and consistently below ½ the MCL/AMCL. A single sample exceeding ½ the MCL/AMCL would trigger reverting to sampling annually. Comments are solicited on the criteria allowing the utility to revert to monitoring once every three years if the average of the initial and three consecutive annual samples is less than ½ the MCL/AMCL.
- Factors affecting State discretion to grant waivers. In addition, the Agency solicits comments on the advisability of reducing the monitoring frequency up to nine years between samples. Comments are solicited on the requirement that all previous samples (that might be used to identify systems which are very unlikely to exceed the MCL/AMCL) must be below ½ the MCL/AMCL in order for a system to qualify for a waiver.
- Allowing States to require the collection of confirmation samples to verify initial sample results as specified by the State, and to use the average of the initial sample and the confirmation samples to determine compliance.

5. Grandfathering of Data

At a State's discretion, sampling data collected since the proposal could be used to satisfy the initial sampling requirements for radon, provided that the system has conducted a monitoring program and used analytical methods that meet proposal requirements. The Agency wants to provide water suppliers with the opportunity to synchronize their radon monitoring program with monitoring for other contaminants and to get an early start on their monitoring program if they wish to do so.

The Agency solicits comments on the advisability of allowing the use of monitoring data obtained since the proposal to satisfy the initial monitoring requirements.

IX. State Implementation

This section describes the regulations and other procedures and policies States have to adopt, or have in place, to implement today's proposed rule. States must continue to meet all other conditions of primacy in 40 CFR part 142.

Section 1413 of the SDWA establishes requirements that a State must meet to obtain or maintain primacy enforcement responsibility (primacy) for its public water systems. These include: (1) Adopting drinking water regulations that are no less stringent than Federal NPDWRs in effect under Section 1412(b) of the Act; (2) adopting and implementing adequate procedures for enforcement; (3) keeping records and making reports available on activities that EPA requires by regulation; (4) issuing variances and exemptions (if allowed by the State) under conditions no less stringent than allowed by Sections 1415 and 1416; (5) adopting and being capable of implementing an adequate plan for the provision of safe drinking water under emergency situations; and (6) adopting authority for administrative penalties.

40 CFR part 142 sets out the specific program implementation requirements for States to obtain primacy for the public water supply supervision (PWSS) program, as authorized under SDWA 1413 of the Act. In addition to meeting the basic primacy requirements, States may be required to adopt special primacy provisions pertaining to a specific regulation. States are required by 40 CFR 142.12 to include these regulation-specific provisions in an application for approval of their program revisions. To maintain primacy for the PWS program and to be eligible for interim primacy enforcement authority for future regulations, States must adopt today's rule, when final, along with the special primacy requirements discussed next. Interim primacy enforcement authority allows States to implement and enforce drinking water regulations once State regulations are effective and the State has submitted a complete and final primacy revision application. Under interim primacy enforcement authority, States are effectively considered to have primacy during the period that EPA is reviewing their primacy revision application.

A. Special State Primacy Requirements

In addition to adopting drinking water regulations at least as stringent as the regulations described in the previous sections, EPA requires that States adopt certain additional provisions related to this regulation, in order to have their drinking water program revision application approved by EPA. States have two options when implementing this rule. States may adopt the AMCL and implement a State-wide MMM program plan or States may adopt the MCL. If a State chooses to adopt the MCL, CWSs in that State have the option to develop and implement a State-approved local MMM program plan and comply with the AMCL.

To ensure that the State program includes all the elements necessary for a complete enforcement program, EPA is proposing that 40 CFR part 142 be amended to require the following in order to obtain primacy for this rule:

(1) Adoption of the promulgated Radon Rule, and

(2) One of the following, depending on which regulatory option the State chooses to adopt:

(a) If a State chooses to develop and implement a State-wide MMM program plan and adopt the AMCL, the primacy application must contain a copy of the State-wide MMM program plan meeting the four criteria in 40 CFR Part 141 Subpart R and the following: a description of how the State will make resources available for implementation of the State-wide MMM program plan, and a description of the extent and nature of coordination between interagency programs (*i.e.*, indoor radon and drinking water programs) on development and implementation of the MMM program plan, including the level of resources that will be made available for implementation and coordination between interagency programs (*i.e.*, indoor air and drinking water programs).

(b) If a State chooses to adopt the MCL, the primacy application must contain a description of how the State will implement a program to approve local CWS MMM program plans prepared to meet the criteria outlined in 40 CFR Part 141 Subpart R. In addition, the primacy application must contain a description of how the State will ensure local CWS MMM program plans are implemented and the extent and nature of coordination between interagency programs (*i.e.*, indoor radon and drinking water programs) on development and implementation of the MMM program, including the level of resources that will be made available for implementation and coordination between interagency programs (*i.e.*, indoor air and drinking water programs), as well as, a description of the reporting and record keeping requirements for the CWSs.

States are required to submit their primacy revision application packages by two years from the date of publication of the final rule in the **Federal Register**. For States adopting the AMCL, EPA approval of a State's primacy revision application is contingent on submission of and EPA approval of the State's MMM program plan. Therefore, EPA is proposing to require submission of State-wide MMM program plans as part of the complete and final primacy revision application. This will enable EPA to review and approve the complete primacy application in a timely and efficient manner in order to provide States with as much time as possible to begin to implement MMM programs. In accordance with Section 1413(b)(1) of SDWA and 40 CFR 142.12(d)(3), EPA is to review primacy applications within 90 days. Therefore, although the SDWA allows 180 days for EPA review and approval of MMM program plans, EPA expects to review and approve State primacy revision applications for the AMCL, including the State-wide MMM program plan, within 90 days of submission to EPA.

EPA is proposing that States notify CWSs of their decision to adopt the MCL or AMCL at the time they submit their primacy application package to EPA (24 months after publication of the final rule). If a State adopts the MCL, CWSs choosing to implement a local CWS MMM program and comply with the AMCL will be required to have completed initial monitoring, notify the State of their intention, and begin developing a plan 4 years after the rule is final. EPA is particularly concerned that these CWSs have sufficient time to develop MMM program plans with local input and allow for State approval. Therefore, it is EPA's expectation that States will be submitting complete and final primacy revision applications by 24 months from the date of publication of the final rule in **Federal Register**. In reviewing any State requests for extensions of time in submitting primacy revision applications, EPA will consider whether sufficient time will be provided to CWSs to develop and get State approval of their local MMM program plans prior to implementation.

B. State Record Keeping Requirements

Today's rule does not include changes to the existing recordkeeping provisions required by 40 CFR 142.14. MMM record keeping requirements will be addressed in each State's primacy revision application submission to meet the special primacy requirements for radon (40 CFR 142.16).

C. State Reporting Requirements

Currently States must report to EPA information under 40 CFR 142.15 regarding violations, variances and exemptions, enforcement actions and general operations of State public water supply programs.

In accordance with the Safe Drinking Water Act (SDWA), EPA is to review State MMM programs at least every five years. For the purposes of this review, the States with EPA-approved MMM program plans shall provide written reports to EPA in the second and fourth years between initial implementation of the MMM program and the first 5-year review period, and in the second and fourth years of every subsequent 5-year review period. EPA will review these programs to determine whether they continue to be expected to achieve risk reduction of indoor radon using the information provided in the two biennial reports. EPA requests comment on this approach. These reports are required to include the following information:

- A quantitative assessment of progress towards meeting the required goals described in Section VI. A., including the number or rate of existing homes mitigated and the number or rate of new homes built radon-resistant since implementation of the States' MMM program: and
- A description of accomplishments and activities that implement the program strategies outlined in the implementation plan and in the two required areas of promoting increased testing and mitigation of existing homes and promoting increased use of radon-resistant techniques in construction of new homes.
- If goals were defined as rates, the State must also provide an estimate of the number of mitigations and radon-resistant new homes represented by the reported rate increase for the two-year period.
- If the MMM program plan includes goals for promoting public awareness of the health effects of indoor radon, testing of homes by the public; testing and mitigation of existing schools; and construction of new public schools to be radon-resistant, the report is also required to include information on results and accomplishments in these areas.

EPA will use this information in discussions and consultations with the State during the five-year review to evaluate program progress and to consider what modifications or adjustments in approach may be needed. EPA envisions this review process will be one of consultation and collaboration between EPA and the States to evaluate the success of the program in achieving the radon risk reduction goals outlined in the approved programs. If EPA determines that a MMM program in not achieving progress towards its goals, EPA and the State shall collaborate to develop modifications and adjustments to the program to be implemented over the five year period following the review. EPA will prepare a summary of the outcome of the program evaluation and the proposed modification and adjustments, if any, to be made by the State.

States that submit a letter to the Administrator by 90 days after publication of the final rule committing to develop an MMM program plan, must submit their first 2-year report by 6.5 years from publication of the final rule. For States not submitting the 90-day letter, but choosing subsequently to submit an MMM program plan and adopt the AMCL, the first 2-year report must be submitted to EPA by 5 years from publication of the final rule. States shall make available to the public each of these two-year reports, as well as the EPA summaries of the five-year reviews of a State's MMM program, within 90 days of completion of the reports and the review.

In primacy States without a State-wide MMM program, the States shall provide a report to EPA every five-years on the status and progress of CWS MMM programs towards meeting their goals. The first of such reports would be due 5 years after CWSs begin implementing a local MMM program which is 5.5 years from publication of the final rule.

D. Variances and Exemptions

Section 1415 of the SDWA authorizes the State to issue variances from NPDWRs (the term "State" is used in this preamble to mean the State agency with primary enforcement responsibility, or "primacy," for the public water supply system program or EPA if the State does not have primacy). The State may issue a variance under Section 1415(a) if it determines that a system cannot comply with an MCL due to the characteristics of its source water, and on condition that the system install BAT. Under Section 1415(a), EPA must propose and promulgate its finding identifying the best available technology, treatment techniques, or other means available for each contaminant, for purposes of Section 1415 variances, at the same time that it proposes and promulgates a maximum contaminant level for such contaminant. EPA's finding of BAT, treatment techniques, or other means for purposes of issuing variances may vary, depending upon the number of persons served by the system or for other physical conditions related to engineering feasibility and costs of complying with MCLs, as considered appropriate by the EPA. The State may not issue a variance to a system until it determines among other things that the variance would not pose an unreasonable risk to health (URTH). EPA has developed draft guidance, "Guidance in Developing Health Criteria for Determining Unreasonable Risks to Health" (USEPA 1990) to assist States in determining when an unreasonable risk to health exists. EPA expects to issue final guidance for determining when URTH levels exist later this year. When a State grants a variance, it must at the same time prescribe a schedule for (1) compliance with the NPDWR and (2) implementation of such additional control measures as the State may require.

Under Section 1416(a), the State may exempt a public water system from any MCL and/or treatment technique requirement if it finds that (1) due to compelling factors (which may include economic factors), the system is unable to comply or develop an alternative supply, (2) the system was in operation on the effective date of the MCL or treatment technique requirement, or, for a newer system, that no reasonable alternative source of drinking water is available to that system, (3) the exemption will not result in an unreasonable risk to health, and (4) management or restructuring changes cannot be made that would result in compliance with this rule. Under Section 1416(b), at the same time it grants an exemption the State is to prescribe a compliance schedule and a schedule for implementation of any required interim control measures. The final date for compliance may not exceed three years after the NPDWR effective date except that the exemption can be renewed for small systems for limited time periods.

EPA will not list "small systems variance technologies", as provided in Section 1415(e)(3) of the Act, since EPA has determined that affordable treatment technologies exist for all applicable system sizes and water quality conditions. As stated in this Section of the Act, if the Administrator finds that small systems can afford to comply through treatment, alternate water source, restructuring, or consolidation, according to the affordability criteria established by the Administrator, then systems are not eligible for small systems variances. Small systems will, however, still be able to apply for "regular" variances and exemptions, pursuant to Sections 1415 and 1416 of the Act.

E. Withdrawing Approval of a State MMM Program

If EPA determines that a State MMM program is not achieving progress towards its MMM goals, and the State repeatedly fails to correct, modify and adjust implementation of its MMM program after notice by EPA, EPA may withdraw approval of the State's MMM program plan. The State will be responsible for notifying CWSs of the Administrator's withdrawal of approval of the State-wide MMM program plan. The CWSs in the State would then be required to comply with the MCL within one year from date of notification, or develop a State-approved CWS MMM program plan. EPA will work with the State to develop a State process for review and approval of CWS MMM program plans that meet the required criteria and establish a time frame for submittal of program plans by CWSs that choose to continue complying with the AMCL. The review process will allow for local public participation in development and review of the program plan.

X. What Do I Need To Tell My Customers? Public Information Requirements

A. Public Notification

Sections 1414(c)(1) and (c)(2) of the SDWA, as amended, require that public water systems notify persons served when violations of drinking water standards occur. EPA recently proposed to revise the current public notification regulations to incorporate new statutory provisions enacted under the 1996 SDWA amendments (64 FR 25963, May 13, 1999). The purpose of public notification is to alert customers in a timely manner to potential risks from violations of drinking water standards and the steps they should take to avoid or minimize such risks.

Today's regulatory action would add violation of the radon NPDWR to the list of violations requiring public notice under the May 13, 1999, proposed public notification rule. Today's action would make three changes to the proposed public notification rule.

- First, Appendix A to Subpart Q would be modified to require a Tier 2 public notice for violations of the MCL and AMCL for all community water systems. Under the proposed rule, Tier 2 public notices would be required for violations and situations with potential to have serious adverse effects on human health. Tier 2 public notices must be distributed within 30 days after the violation is known, and must be repeated every three months until the violation is resolved.
- Second, Appendix A would also be modified to require a Tier 3 public notice for all radon monitoring and testing procedure violations and for violations of the Multimedia Mitigation (MMM) Program Plan. Tier 3 public notices must be distributed within a year of the violation and could, at the water system's option, be included in the annual Consumer Confidence Report (CCR).
- Third, Appendix B to Subpart Q would be modified to add standard health effects language, which public water systems are required to use in their notices when violations of the AMCL or MMM occur. EPA proposes that the standard health effects language for these violations, to be included in CCR annual reports and public notices. The language for violation of the (A)MCL would be as follows: "People who use drinking water containing radon in excess of the (A)MCL for many years may have an increased risk of getting lung and stomach cancer." The language for violation of the MMM would be as follows: "Your water system is not complying with requirements to promote the reduction of lung cancer risks from radon in indoor air, which is a problem in some homes. Radon is a naturally occurring radioactive gas which may enter homes from the surrounding soil and may also be present in drinking water. Because your system is not complying with applicable requirements, it may be required to install water treatment technology to meet more stringent standards for radon in drinking water. The best way to reduce radon risk is to test your home's indoor air and, if elevated levels are found, hire a qualified contractor to fix the problem. For more information, call the National Safety Council's Radon Hotline at 1–800–SOS–RADON." The standard health effects language public water systems are to use in their public notice would be identical to that used in the annual CCR.

The final public notification rule is expected to be published around December, 1999, well in advance of the August, 2000, deadline for the final radon regulation. The final public notification requirements for radon, therefore, will be published with the final radon rule. The Agency will republish the tables in Appendices A and B to Subpart Q of Part 141 with all necessary changes in the final rule.

B. Consumer Confidence Report

Section 1414(d) of the SDWA requires that all community water systems provide annual water quality reports (or consumer confidence reports (CCRs)) to their customers. In their reports, systems must provide, among other things, the levels and sources of all detected contaminants, the potential health effects of any contaminant found at levels that violate EPA or State rules, and short educational statements on contaminants of particular interest.

Today's action updates the standard CCR rule requirements in subpart O and adds special requirements that reflect the multimedia approach of this rule. The intent of these provisions is to assist in clearer communication of the relative risks of radon in indoor air from soil and from drinking water, and to encourage public participation in the development of the State or CWS MMM program plans. Systems that detect radon at a level that violates the A/MCL would have to include in their report a clear and understandable explanation of the violation including: the length of the violation, actions taken by the system to address the violation, and the potential health effects (using the language proposed today for Appendix C to subpart O: "People who use drinking water containing radon in excess of the (A)MCL for many years may have an increased risk of getting lung and stomach cancer"). This approach is comparable to that used for other drinking water contaminants.

In addition, recognizing the novelty of the MMM approach and the interest that consumers may have in participating in the design of the MMM program, today's action also proposes that any system that has ground water as a source must include information in its report in the years between publication of the final rule and the date by which States, or systems, will be required to implement an MMM program. This information would include a brief educational statement on radon risks, explaining that the principal radon risk comes from radon in indoor air, rather than drinking water, and for that reason, radon risk reduction efforts may be focused on indoor air rather than drinking water. This information will also note that many States and systems are in the process of creating programs to reduce exposure to radon, and encourage readers to call the Radon Hotline (800–SOS–RADON) or visit EPA's radon web site (www.epa.gov/iaq/radon) for more information. A system would be able to use language provided in the proposed rule by EPA or could chose to tailor the wording to its specific local circumstances in consultation with the primacy agency. EPA recognizes that this creates a slight additional burden on community water system operators, but believes that the value of strong public support for, and participation in, the creation of the MMM program outweighs this burden. EPA also recognizes that this notice may provoke some confusion, since CCRs would alert consumers to the risks presented by a contaminant which most systems have never monitored in their water, although the notice would state that the system would be testing and would provide customers with the results. EPA is requesting comment on this proposed notice.

Finally, the Agency will republish the tables in Appendices A, B, and C to Subpart O of Part 141 with all necessary changes in the final rule.

Risk Assessment and Occurrence

XI. What Is EPA's Estimate of the Levels of Radon in Drinking Water?

A. General Patterns of Radon Occurrence

Radon levels in ground water in the United States are generally highest in New England and the Appalachian uplands of the Middle Atlantic and Southeastern States. There are also isolated areas in the Rocky Mountains, California, Texas, and the upper Midwest where radon levels in ground water tend to be higher than the United States average. The lowest ground water radon levels tend to be found in the Mississippi Valley, lower Midwest, and Plains States. The following map shows the general patterns of radon occurrence in those States for which data are available.

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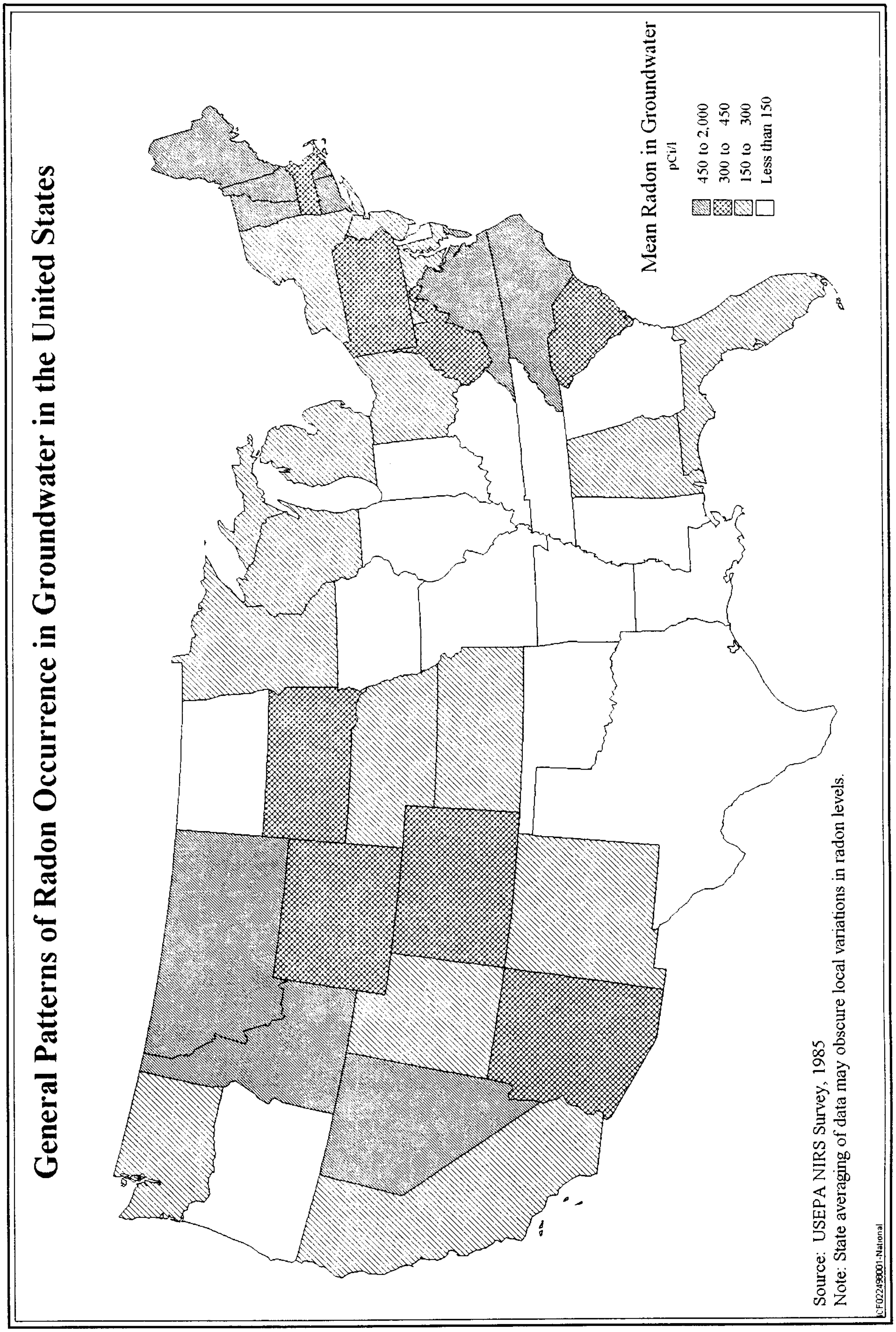

General Patterns of Radon Occurrence in Groundwater in the United States

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In addition to large-scale regional variation, radon levels in ground water vary significantly over a smaller area. Local differences in geology tend to greatly influence the patterns of radon levels observed at specific locations. (This means, for example, that not all radon levels in New England are high and not all radon levels in the Gulf Coast region are low). Over small distances, there is often no consistent relationship between radon levels in ground water and uranium or other radionuclide levels in the ground water or in the parent bedrock (Davis and Watson 1989). Similarly, no significant geographic correlation has been found between radon levels in groundwater systems and the levels of other inorganic contaminants. Radon may be found in groundwater systems where other contaminants (for example, arsenic) also occur. However, finding a high (or low) level of radon does not indicate that a high (or low) level of other contaminants will also be found. Similarly, there is little evidence that radon occurrence is correlated with the presence of organic pollutants. In estimating the costs of radon removal, EPA has taken into account the fact that other contaminants, such as iron and manganese, may also be present in the water. High levels of iron and manganese may complicate the process of radon removal and increase the costs of mitigation.

Radon is released rapidly from surface water. Therefore, radon levels in supplies that obtain their water from surface sources (lakes or reservoirs) are very low compared to groundwater levels.

Because of its short half life, there are relatively few man-made sources of radon exposure in ground water. The most common man-made sources of radon ground water contamination are phosphate or uranium mining or milling operations and wastes from thorium or radium processing. Releases from these sources can result in high ground water exposures, but generally only to very limited populations; for instance, to persons using a domestic well in a contaminated aquifer as a source of potable water (USEPA 1994a).

B. Past Studies of Radon Levels in Drinking Water

A number of studies of radon levels in drinking water were undertaken in the 1970s and early 1980s. Most of these studies were limited to small geographic areas, or addressed systems that were not representative of community systems throughout the U.S. The first attempt to develop a comprehensive understanding of radon levels in public water supplies was the National Inorganics and Radionuclides Survey (NIRS), which was undertaken by the EPA in 1983–1984. As part of NIRS, radon samples were analyzed from 1,000 community groundwater systems throughout the United States. The size distribution of systems sampled was the same as the size distribution of groundwater systems in U.S., and the geographic distribution was approximately consistent with the regional distribution of systems. Because of the limited number of samples, however, the number of radon measurements in some States was quite small. Table XI.B.1 summarizes the regional patterns of radon in drinking water supplies as seen in the NIRS database.

TABLE XI.B.1.—RADON IN COMMUNITY GROUND WATER SYSTEMS BY REGION (ALL SYSTEM SIZES)

Region	Arithmetic mean (pCi/L)	Geometric mean (pCi/L)	Geometric standard deviation (pCi/L)
Appalachian	1,127	333	4.76
California	629	333	3.09
Gulf Coast	263	125	3.38
Great Lakes	278	151	3.01
New England	2,933	1,214	3.77
Northwest	222	161	2.23
Plains	213	132	2.65
Rocky Mountains	607	361	2.77

Source: USEPA 1999g.

Note: These distributions are described in two ways. First, the arithmetic means (average values) are given. In addition, the geometric mean and geometric standard deviation are given. This approach is taken because the distributions of radon in groundwater systems are not "normal" bell-shaped curves. Instead, like many environmental data sets, it was found that the √logarithms of the radon concentrations were normally distributed ("lognormal distribution.") The geometric mean corresponds to the center of a bell-shaped "normal" distribution when radon concentrations are expressed in logarithms. The geometric standard deviation is a measure of the spread of the bell-shaped curve, expressed in logarithmic form.

The NIRS has the disadvantage that the samples were all taken from within the water distribution systems, making estimation of the naturally occurring influent radon levels difficult. In addition, the NIRS data provide no information to allow analysis of the variability of radon levels over time or within individual systems. Thus, while the NIRS data provide statistically valid estimates of radon levels in the systems that were sampled, they do not adequately represent radon levels in some individual States, especially in large systems.

The NIRS data formed the basis for EPA's first estimates of the levels of radon in community groundwater systems in the United States (Wade Miller 1990). They formed the basis for estimating the impacts of EPA's 1991 Proposed Rule. These estimates were updated in 1993, using improved statistical methods to estimate the distributions of radon in different size systems (Wade Miller 1993.)

C. EPA's Most Recent Studies of Radon Levels in Ground Water

EPA's current re-evaluation of radon occurrence in ground water (USEPA 1999g) uses data from a number of additional sources to supplement the NIRS information and to develop estimates of the national distribution of radon in community ground water systems of different sizes. EPA gathered data from 17 States where radon levels were measured at the wellhead, rather than in the distribution systems. The Agency then evaluated the differences between the State (wellhead) data and the NIRS (distribution system) data. These differences were then used to adjust the NIRS data to make them more representative of ground water radon levels in the States where no direct measurements at the wellhead had been made. EPA solicits any additional data on radon levels in community water systems, particularly in the largest size categories.

Table XI.C.1 summarizes EPA's latest estimates of the distributions of radon levels in ground water supplies of different sizes. It also provides information on the populations exposed to radon through community water systems (CWS). In this table, radon levels and populations are presented for systems serving population ranges from 25 to greater than 100,000 customers. The CWSs are broken down into the following system size categories:

- Very very small systems (25–500 people served), further subdivided into 25–100 and 101–500 ranges, in response to comments received on the 1991 proposal;
- Very small systems (501–3,300 people);
- Small systems (3,301–10,000 people);
- Medium systems (10,001–100,000 people); and
- Large systems (greater than 100,000 people).

TABLE XI.C.1.—RADON DISTRIBUTIONS IN COMMUNITY GROUNDWATER SYSTEMS

	System Size (Population Served)					
	25–100	101–500	501–3,300	3,301–10,000	>10,000	All systems
Total Systems	14,651	14,896	10,286	2,538	1,536	43,907
Geometric Mean Radon Level, pCi/L	312	259	122	124	132	232
Geometric Standard Deviation	3.0	3.3	3.2	2.3	2.3	3.0
Arithmetic Mean	578	528	240	175	187	442
Population Served (Millions)	0.87	3.75	14.1	14.3	55.0	88.1
Radon Level, pCi/L	Proportions of Systems Exceeding Radon Levels (percent)					
100	84.7	78.7	56.9	60.4	62.9	74.0
300	51.4	45.1	22.1	14.3	16.2	39.0
500	33.6	29.1	11.4	4.6	5.5	24.2
700	23.4	20.3	6.8	1.8	2.3	16.5
1000	14.7	12.9	3.6	0.6	0.8	10.2
2000	4.7	4.4	0.8	0.0	0.1	4.9
4000	1.1	1.1	0.1	0.0	0.0	0.8

Sources: USEPA 1999g; Safe Drinking Water Information System (1998).

Systems were broken down in this fashion because EPA's previous analyses have shown that the distributions of radon levels are different in different size systems. In the updated occurrence analysis, insufficient data were available to accurately assess radon levels in various subcategories of largest systems. Thus, data from the two largest size categories were pooled to develop exposure estimates.

D. Populations Exposed to Radon in Drinking Water

Based on data from the Safe Drinking Water Information System (SDWIS), the Agency estimates that approximately 88.1 million people were served by community ground water systems in the United States in 1998. Using the data in Table XI.C.1, systems serving more than 500 people account for approximately 95 percent of the population served by community ground water systems, even though they represent only about 33 percent of the total active systems. The largest systems (those serving greater than 10,000 people) serve approximately 62.5 percent of the people served by community ground water systems, even though they account for only 3.5 percent of the total number of systems.

As noted previously, the average radon levels vary across the system size categories. As shown in Table XI.C.1, the average system geometric mean radon levels range from approximately 120 pCi/L for the larger systems to 312 pCi/L for the smallest systems. The average arithmetic mean values for the various system size categories range from 175 pCi/L to 578 pCi/L, and the population-weighted arithmetic mean radon level across all the community ground water supplies is 213 pCi/L (calculations not shown). The bottom panel of Table XI.C.1 shows the proportions of the systems with average radon levels greater than selected values.

Table XI.D.1 presents the total populations in homes served by community ground water systems at different radon levels, broken down by system size category. These data show that approximately 20 percent of the total population served by community ground water systems are served by systems where the average radon levels entering the system exceed 300 pCi/L and 64 percent of this population are served by systems with average radon levels above 100 pCi/L. Less than one-tenth of one percent of the population is served by systems obtaining their water from sources with radon levels above 4,000 pCi/L.

TABLE XI.D.1.—POPULATION EXPOSED ABOVE VARIOUS RADON LEVELS BY COMMUNITY GROUND WATER SYSTEM SIZE (THOUSANDS)

Radon level (pCi/L)	Very very small		Very Small	Small	Medium	Large	Total
	25–100	101–500	501–3,300	3,301–10K	10K–100K	>100K	
4,000	9.4	46	20	0.2	0.9	0.4	77.2
2,000	41	183	119	5.7	21.7	11.0	381
1,000	128	541	513	85.5	289	147	1,695
700	202	848	962	267	859	436	3,558
500	290	1,210	1,620	672	2,070	1,050	6,893
300	445	1,880	3,140	2,080	6,060	3,070	16,641
100	733	3,290	8,080	8,760	23,400	11,900	56,054

XII. What Are the Risks of Radon in Drinking Water and Air?

A. Basis for Health Concern

The potential hazard of radon was first identified in the 1940s when an increased incidence of lung cancer in Bohemian underground miners was shown to be associated with inhalation of high levels of radon-222 in the mines. By the 1950s, the hazard was shown to be due mainly to the short half-life progeny of radon-222. Based on a clear relationship between radon exposure and risk of lung cancer in a number of studies in miners, national and international health organizations have concluded that radon is a human carcinogen. In 1988, the International Agency for Research on Cancer (IARC 1988) convened a panel of world experts who agreed unanimously that sufficient evidence exists to conclude that radon causes cancer in humans and in experimental animals. The Biological Effects of Ionizing Radiation (BEIR) Committee (NAS 1988, NAS 1999a), the International Commission on Radiological Protection (ICRP 1987), and the National Council on Radiation Protection and Measurement (NCRP 1984) also have reviewed the available data and agreed that radon exposure causes cancer in humans. EPA has concurred with these determinations and classified radon in Group A, meaning that it is considered by EPA to be a human carcinogen based on sufficient evidence of cancer in humans. After smoking, radon is the second leading cause of lung cancer deaths in the United States (NAS 1999a).

Most of the radon that people are exposed to in indoor and outdoor air comes from soil. However, radon in ground water used for drinking or other indoor purposes can also be hazardous. When radon in water is ingested, it is distributed throughout the body. Some of it will decay and emit radiation while in the body, increasing the risk of cancer in irradiated organs (although this increased risk is significantly less than the risk from inhaling radon). Radon dissolved in tap water is released into indoor air when it is used for showering, washing or other domestic uses, or when the water is stirred, shaken, or heated before being ingested. This adds to the airborne radon from other sources, increasing the risk of lung cancer (USEPA 1991, 1994a; NAS 1999b).

B. Previous EPA Risk Assessment of Radon in Drinking Water

1. EPA's 1991 Proposed Radon Rule

Because initial information on the cancer risks of radon came from studies of underground miners exposed to very high radon levels, not much consideration was given to non-occupational radon exposure until recently. As new miner groups at lower radon exposure levels were added to the data base, it became evident that radon exposures in indoor air, outdoor air, and drinking water might be important sources of risk for the U.S. population. In 1991, as part of developing a regulation for radionuclides and radon in water as required by the 1986 Safe Drinking Water Act, EPA drafted the Radon in Drinking Water Criteria Document (USEPA 1991) to assess the ingestion and inhalation risk associated with exposure to radon in drinking water. EPA estimated that a person's risk of fatal cancer from lifetime use of drinking water containing one picocurie of radon per liter (1 pCi/L) is close to 7 chances in 10 million ($7 \times 10-^{-7}$). Based on this and other considerations, EPA proposed a rule for regulating radon levels in public water systems (56 FR 33050).

2. SAB Concerns Regarding the 1991 Proposed Radon Rule

The Radiation Advisory Committee of EPA's Science Advisory Board (SAB) reviewed EPA's draft criteria document and proposed rule and identified a number of issues that had not been adequately addressed, including: (a) Uncertainties associated with the models, model parameters, and final risk estimates; (b) high exposure from water at the point of use (*e.g.,* shower); (c) risks from the disposal of treatment byproducts; and (d) occupational exposure due to regulation and removal of radon in drinking water. The SAB recommended that EPA investigate these issues before finalizing the radon rule. The EPA considered SAB's recommendations in developing the current proposal.

3. 1994 Report to Congress

In 1992, Congress passed Public Law 102–389 (the Chafee-Lautenberg Amendment to EPA's Appropriation Bill). This law directs the Administrator of the EPA to report to Congress on EPA's findings regarding the risks of human exposure to radon and their associated uncertainties, the costs for controlling or mitigating that exposure, and the risks posed by treating water to remove radon.

In response to the SAB's comments and the Chafee-Lautenberg Amendment, EPA drafted a report entitled Uncertainty Analysis of Risks Associated with Radon in Drinking Water (USEPA 1993b) and presented it to the SAB in February 1993. This document evaluated the variability and uncertainty in each of the factors needed to calculate human cancer risk from water-borne radon in residences served by community groundwater systems, and used Monte Carlo simulation techniques to derive quantitative confidence bounds for the risk estimates for each of the exposure routes to water-borne radon. In addition, the report summarized the risk estimates from exposure to radon in indoor and outdoor air.

Based on the data available at the time, EPA estimated that the total number of fatal cancers that will occur as a result of exposure to water-borne radon in homes supplied by community groundwater systems was 192 per year. EPA noted that the risk from water-borne radon is small compared to the risk of soil-derived radon in indoor air (13,600 lung cancer cases per year) or in outdoor air (520 lung cancer deaths per year) (USEPA 1992b, 1993b).

The EPA included the findings of this uncertainty analysis with the SAB review comments in the Report to the United States Congress on Radon in Drinking Water: Multimedia Risk and Cost Assessment of Radon (USEPA 1994a). This report also included an assessment of the risk from exposure to radon at drinking water treatment facilities. The SAB reviewed the report prepared by EPA, and commended the EPA's methodologies employed in the uncertainty analysis and the exposure assessment of radon at the point of use (*e.g.* showering). However, the SAB stated that the estimates of risk from ingested radon may have additional uncertainties in dose estimation and in the use of primarily the atomic bomb survivor exposure (gamma emission with low linear energy transfer) in deriving the organ-specific risk per unit dose for from radon and progeny (alpha particle emission with high linear energy transfer). The SAB also questioned EPA's estimates of the number of community water supplies affected, and the extrapolation of the risk of lung cancer associated with the high radon exposures of uranium miners to the low levels of exposure experienced in domestic environments. The SAB recommended that the Agency use a relative risk orientation as an important consideration in making risk reduction decisions on all sources of risks attributable to radon. Based on the comments and recommendations of the SAB, EPA revised several of the distributions used in the Monte Carlo analysis and finalized the Uncertainty Analysis of Risks Associated with Exposure to Radon in Drinking Water (USEPA 1995).

C. NAS Risk Assessment of Radon in Drinking Water

1. NAS Health Risk and Risk-Reduction Benefit Assessment Required by the 1996 Amendments to the Safe Drinking Water Act

The 1996 amendments to the Safe Drinking Water Act required EPA to arrange with the National Academy of Sciences (NAS) to conduct a risk assessment of radon in drinking water and an assessment of the health-risk reduction benefits associated with various measures to reduce radon concentrations in indoor air. The law also directed EPA to promulgate an alternative maximum contaminant level (AMCL) if the proposed MCL is less than the concentration of radon in water ''necessary to reduce the contribution of radon in indoor air from drinking water to a concentration that is equivalent to the national average concentration of radon in outdoor air.''

2. Charge to the NAS Committee

In accordance with the requirements of the 1996 amendments to the SDWA, in February 1997, EPA funded the NAS National Research Council to establish a multidisciplinary committee of the Board of Radiation Effects Research. This Committee on Risk Assessment of Exposure to Radon in Drinking Water (the NAS Radon in Drinking Water committee) was charged to use the best available data and methods to provide the following:

(a) The best estimate of the central tendency of the transfer factor for radon from water to air, along with an appropriate uncertainty range,

(b) Estimates of unit cancer risk (*i.e.*, the risk from lifetime exposure to water containing 1 pCi/L) for the inhalation and ingestion exposure routes, both for the general population and for subpopulations within the general population (*e.g.*, infants, children, pregnant women, the elderly, individuals with a history of serious illness) that are identified as likely to be at greater risk due to exposure to radon in drinking water than the general population,

(c) Unit cancer risks from inhalation exposure for people in different smoking categories,

(d) Descriptions of any teratogenic and reproductive effects in men and women due to exposure to radon in drinking water,

(e) Central estimates for a population-weighted average national ambient (outdoor) air concentration for radon, with an associated uncertainty range.

The NAS Radon in Drinking Water committee was also asked to estimate health risks that might occur as the result of compliance with a primary drinking water regulation for radon. The committee was to assess the health risk reduction benefits associated with various mitigation measures to reduce radon levels in indoor air.

3. Summary of NAS Findings

The NAS completed its charge and issued a report entitled ''Risk Assessment of Radon in Drinking Water'' (NAS 1999b). The NAS report provides detailed descriptions of the methods and assumptions employed by the NAS Radon in Drinking Water committee in completing its evaluation. The following text provides a summary of the NAS report.

(a) National Average Ambient Radon Concentration. Because radon levels in outdoor air vary from location to location, the NAS Radon in Drinking Water committee concluded that available data are not sufficiently representative to calculate a population-weighted annual average ambient radon concentration. Based on the data that are available, the NAS Radon in Drinking Water committee concluded that the best estimate of an unweighted arithmetic mean radon concentration in ambient (outdoor) air in the United States is 15 Bq/m^3 (equal to 0.41 pCi/L of air), with a confidence range of 14 to 16 Bq/m^3 (0.38–0.43 pCi/L air).

(b) Transfer Factor. The relationship between the concentration of radon in water and the average indoor air concentration of water-derived radon is described in terms of the transfer factor (pCi/L in air per pCi/L in water). Most researchers who have investigated this variable in residences find that it can be described as a lognormal distribution of values, most conveniently characterized by the arithmetic mean (AM) and the standard deviation (Stdev), or by the geometric mean (GM) and the geometric standard deviation (GSD). The NAS Radon in Drinking Water committee performed an extensive review of both measured and calculated values of the transfer factor in residences, with the results summarized in the following Table XII.1:

TABLE XII.1.—MEASURED AND MODELED TRANSFER FACTORS

Approach	AM	Stdev	GM	GSD
Measured	0.87×10^{-4}	1.2×10^{-4}	0.38×10^{-4}	3.3
Modeled	1.2×10^{-4}	2.4×10^{-4}	0.55×10^{-4}	3.5

[a] Calculated from, GM and GSD.

The committee concluded that there is reasonable agreement between the average value of the transfer factor estimated by the two approaches, and identified 1 in 10,000 (1.0×10^{-4}) as the best central estimate of the transfer factor for residences, with a confidence bound of about 0.8 to 1.2×10^{-4}. This central tendency value is the same as has been used in previous assessments (USEPA 1993b, 1995).

Based on this transfer factor, the NAS committee concluded that the AMCL for radon in drinking water would be 150,000 Bq/m^3 (about 4,000 pCi/L). That is, a concentration of 4,000 pCi/L of radon in water is expected to increase the concentration of radon in indoor air by an amount equal to that in outdoor air.

(c) Biologic Basis of Risk Estimation. Both the BEIR VI Report (NAS 1999a) and their report on radon in drinking water (NAS 1998b) represent the most definitive accumulation of scientific data gathered on radon since the 1988 NAS BEIR IV (NAS 1988). These committees' support for the use of linear non-threshold relationship for radon exposure and lung cancer risk came primarily from their review of the mechanistic information on alpha-particle-induced carcinogenesis, including studies of the effect of single versus multiple hits to cell nuclei.

The NAS BEIR VI Committee (NAS 1999a) conducted an extensive review of information on the cellular and molecular mechanism of radon-induced cancer in order to help support the assessment of cancer risks from low levels of radon exposure. In the BEIR VI report (NAS 1999a), the NAS concluded that there is good evidence that a single alpha particle (high-linear energy transfer radiation) can cause major genomic changes in a cell, including mutation and transformation that potentially could lead to cancer. Alpha particles, such as those that are emitted from the radon decay chain, produce dense trails of ionized molecules when they pass through a cell, causing cellular damage. Alpha particles passing through the nucleus of a cell can damage DNA. In their report, the BEIR VI Committee noted that even if substantial repair of the genomic damage were to occur, ''the passage of a single alpha particle has the potential to cause irreparable damage in cells that are not killed''. Given the convincing evidence that most cancers originate from damage to a single cell, the Committee went on to conclude that ''On the basis of these [molecular and cellular] mechanistic considerations, and in the absence of credible evidence to the contrary, the Committee adopted a linear non-threshold model for the relationship between radon exposure and lung-cancer risk. The Committee also noted that epidemiological data relating to low radon exposures in mines also indicate that a single alpha track through the cell may lead to cancer. Finally, while not definitive by themselves, the results from residential case-control studies provide some direct support for the conclusion that environmental levels of radon pose a risk of lung cancer. However, the BEIR VI Committee recognized that it could not exclude the possibility of a threshold relationship between exposure and lung cancer risk at very low levels of radon exposure.

The NAS Committee on radon in drinking water (NAS 1999b) reiterated the finding of the BEIR VI Committee's comprehensive review of the issue, that a ''mechanistic interpretation is consistent with linear non-threshold relationship between radon exposure and cancer risk''. The committee noted that the ''quantitative estimation of cancer risk requires assumptions about the probability of an exposed cell becoming transformed and the latent period before malignant transformation is complete. When these values are known for singly hit cells, the results might lead to reconsideration of the linear no-threshold assumption used at present.@ EPA recognizes that research in this area is on-going but is basing its regulatory decisions on the best currently available science and recommendations of the NAS that support use of a linear non-threshold relationship. EPA recognizes that research in this area is on-going but is basing its regulatory decisions on the best currently available science and recommendations of the NAS that support use of a linear non-threshold relationship.

(d) Unit Risk from Inhalation Exposure to Radon Progeny. The calculation of the unit risk from inhalation of radon progeny derived from water-borne radon depends on four key variables: (1) The transfer factor that relates the concentration of radon in air to the concentration in water, (2) the equilibrium factor (the level of radon progeny present compared to the theoretical maximum amount), (3) the occupancy factor (the fraction of full time that a person spends at home) and (4) the risk of lung cancer per unit exposure (the risk coefficient). The values utilized by NAS for each of these factors are summarized next.

Transfer Factor

The NAS Radon in Drinking Water committee (NAS 1999b) reviewed available data and concluded that the best estimate of the transfer factor is 1.0×10^{-4} pCi/L air per pCi/L water.

Equilibrium Factor

At radiological equilibrium, 1 pCi/L of radon in air corresponds to a concentration of 0.010 Working Levels (WL) of radon progeny. One WL is defined as any combination of radioactive chemicals that result in an emission of 1.3×10^5 MeV of alpha particle energy. One WL is approximately the total amount of energy released by the short-lived progeny in equilibrium with 100 pCi of radon. Under typical household conditions, processes such as ventilation and plating out of progeny prevent achievement of equilibrium, and the level of radon progeny present is normally less than 0.010 WL. The equilibrium factor (EF) is the ratio of the alpha energy actually present in respirable air compared to the theoretical maximum at equilibrium. Based on a review of measured values in residences, USEPA (1993b, 1995) identified a value of 0.4 as the best estimate of the mean, with a credible range of 0.35 to 0.45. NAS (1999a, 1999b) reviewed the data and also selected a value of 0.4 as the most appropriate point estimate of EF.

Occupancy Factor

The occupancy factor (the fraction of time that a person spends at home) varies with age and occupational status. Studies on the occupancy factor have been reviewed by EPA (USEPA 1992b, 1993b, 1995), who found that a value of 0.75 is the appropriate point estimate of the mean with a credible range of 0.65–0.80. Based on a review of available data, both the BEIR VI committee (NAS 1999a) and the NAS Radon in Drinking Water committee (NAS 1999b) identified an occupancy factor of 0.7 as the best estimate to employ in calculation of the inhalation unit risk from inhalation of radon progeny.

Risk of Lung Cancer Death per Unit Exposure (Risk Coefficient)

There are extensive data on humans (mainly from studies of underground miners) establishing that inhalation exposure to radon progeny causes increased risk of lung cancer (NAS 1999a, 1999b). The basic approach used by NAS to quantify the risk of fatal cancer (specifically death from lung cancer) from inhalation of radon progeny in air was to employ empirical dose-response relationships derived from studies of humans exposed to radon progeny in the environment. The most recent quantitative estimate of the risk of lung cancer associated with inhalation of radon progeny has been conducted by the BEIR VI committee (NAS 1999a), and this analysis was employed by the NAS Radon in Drinking Water committee (NAS 1999b). The BEIR VI committee reviewed all of the most current data from studies of humans exposed to radon, including cohorts of underground miners and residents exposed to radon in their home, as well as studies in animals and in isolated cells. Because of differences in exposure level and duration, studies of residential radon exposure would normally be preferable to studies of miners for quantifying risk to residents from radon progeny in indoor air. However, the BEIR VI committee found that the currently available epidemiological studies of residents exposed in their homes are not sufficient to develop reliable quantitative exposure-risk estimates because (a) the number of subjects is small, (b) the difference between exposure levels is limited, and (c) cumulative radon exposure estimates are generally incomplete or uncertain. Therefore, the BEIR VI committee focused their analysis on studies of radon-exposed underground miners.

The method used by the BEIR VI committee was essentially the same as used previously by the BEIR IV committee (NAS 1988), except that the database on radon risk in underground miners is now much more extensive, including 11 cohorts of underground miners, which, in all, include about 2,700 lung cancers among 68,000 miners, representing nearly 1.2 million person-years of observations. Details of these 11 cohorts are presented in the NAS BEIR VI Report (NAS 1999a). For historical reasons, the measure of exposure used in these studies is the Working Level Month (WLM), which is defined as 170 hours of exposure to one Working Level (WL) of radon progeny.

Based on evidence that risk per unit exposure increased with decreasing exposure rate or with increasing exposure duration (holding cumulative exposure constant), the BEIR VI committee modified the previous risk model to include a term to account for this ''inverse dose rate'' effect. Because the adjustment could be based on either the concentration of radon progeny or the duration of exposure, there are two alternative forms of the preferred model—the ''exposure-age-concentration'' model, and the ''exposure-age-duration'' model. For brevity, these will generally be referred to here as the ''concentration'' and ''duration'' models.

Mathematically, both models can be represented as:

$$RR=1+ERR=1+\beta(\omega_{5\text{-}14}+\theta_{15\text{-}24}\omega_{15\text{-}24}+\theta_{25+}\omega_{25+})\phi_{age}\gamma_Z \qquad (1)$$

Where:

RR=relative risk of lung cancer in a person due to above-average radon exposure compared to the average background risk for a similar person in the general population

ERR=Excess relative risk (the increment in risk due to the above-average exposure to radon)

β=exposure-response parameter (excess relative risk per WLM)

$\omega_{5\text{-}14}$=exposures (WLM) incurred from 5–14 years prior to the current age

$\omega_{15\text{-}24}$=exposures (WLM) incurred from 15–24 years prior to the current age

ω_{25+}=exposures (WLM) incurred 25 or more years prior to the current age

$\theta_{15\text{-}24}$=time-since-exposure factor for risk from exposures incurred 15–24 years or more before the attained age

θ_{25+}=time-since-exposure factor for risk from exposures incurred 25 or more years or more before the attained age

ϕ_{age}=effect-modification factor for attained age

γ_Z=effect-modification factor for exposure rate or exposure duration

The BEIR VI committee used a two-stage approach for combining information from the 11 miner studies to derive parameters for the concentration and duration risk models. First, estimates of model parameters were derived for each study cohort, and then population-weighted averages of the parameters were calculated across studies to derive an overall estimate that takes variation between and within cohorts into account. The results of the pooled analysis of all of the miner data indicated that, for a given level of exposure to radon, the excess relative risk of lung cancer decreases with increasing time since exposure, decreases as a function of increased attained age, increases with increasing duration of exposure, and decreases with increasing exposure rate (the inverse dose rate effect).

The BEIR VI committee applied the risk models to 1985–89 U.S. mortality data to estimate individual and population risks from radon in air. At the individual level, the committee estimated the lifetime excess relative risk (ERR), which is the percent increase in the lifetime probability of lung cancer death from indoor radon exposure. For population risks, the committee estimated attributable risk (AR), which indicates the proportion of lung-cancer deaths that theoretically may be reduced by reduction of indoor radon concentrations to outdoor levels.

Extrapolation From Mines to Homes

Because of a number of potential differences between mines and homes, exposures to equal levels of radon progeny may not always result in equal doses to lung cells. The ratio of the dose to lung cells in the home compared to that in mines is described by the K factor. Based on the best data available at the time, NAS (1991) had previously concluded that the dose to target cells in the lung was typically about 30 percent lower for a residential exposure compared to an equal WLM exposure in mines (*i.e.*, K = 0.7). The BEIR VI committee re-examined the issue of the relative dosimetry in homes and mines. In light of new information regarding exposure conditions in home and mine environments, the committee concluded that, when all factors are taken into account, the dose per WLM is nearly the same in the two environments (*i.e.*, a best estimate for the K-factor is about 1) (NAS 1999a). The major factor contributing to the change was a downward revision in breathing rates for miners. Thus, for calculation of risks from residential exposures, Equation 1 can be applied directly without adjustment.

Combined Effect of Smoking and Radon

Because of the strong influence of smoking on the risk from radon, the BEIR VI committee (NAS 1999a) evaluated risk to ever-smokers and never-smokers separately. The committee had information on 5 of the miner cohorts, from which they concluded that the combined effects of radon and smoking were more than additive but less than multiplicative. As a best estimate the committee determined that never-smokers should be assigned a relative risk coefficient (β) about twice that for ever-smokers, in each of the two models defined previously. This means that the attributable risk, or the proportion of all lung cancers attributable to radon, is about twice as high for never-smokers as ever-smokers. Nevertheless, because the incidence of lung cancer is much greater for ever-smokers than never-smokers, the probability of a radon induced lung cancer is still much higher for ever-smokers. This higher risk in ever-smokers arises from the synergism between radon and cigarette smoke in causing lung cancer.

Based on the BEIR VI lifetime relative risk results, the NAS Radon in Drinking Water committee (NAS 1999b) calculated the lifetime risk (per Bq/m^3 air) for each of the two models using the following basic equation:

Excess lifetime risk=(Baseline risk)* (LRR–1)

Where LRR=lifetime relative risk

Baseline lung cancer risk values used by the NAS Radon in Drinking Water committee (NAS 1999b) are summarized in Table XII.2.

TABLE XII.2.—BASELINE LUNG CANCER RISK

Gender	Smoking prevalence	Ever-smokers [1]	Never-smokers
Male	0.58	0.116	0.0091
Female	0.42	0.068	0.0059

[1] Ever-smokers were defined as persons who had smoked at least 100 cigarettes in their entire life (CDC 1995).

The NAS Radon in Drinking Water committee (NAS 1999b) adopted the average of the results from each of the two models as the best estimate of lifetime risk from radon progeny.

Results: Inhalation Unit Risk for Water-Borne Radon Progeny

Based on the inputs and approaches summarized in the previous sections, NAS calculated the inhalation unit risk for radon progeny, by smoking category, with the results described in Table XII.3:

TABLE XII.3.—LIFETIME UNIT RISK

Smoking category	per Bq/m^3 in air	per pCi/L in water	Lifetime (yrs)	Annual unit risk (per pCi/L in water)	Inhalation risk coefficient (per WLM)
Combined	1.6×10^{-4}	5.93×10^{-7}	74.9	7.92×10^{-9}	5.49×10^{-4}
Ever Smokers	2.6×10^{-4}	9.63×10^{-7}	73.7	1.31×10^{-8}	9.07×10^{-4}
Never Smokers	0.5×10^{-4}	1.85×10^{-7}	76.1	2.43×10^{-9}	1.68×10^{-4}

The NAS Radon in Drinking Water committee (NAS 1999b) estimated that the uncertainty around the inhalation risk coefficient for radon progeny can be characterized by a lognormal distribution with a GSD of 1.2 (based on the duration model) to 1.3 (based on the concentration model). This corresponds to an uncertainty range for the combined population of about 3.4 × 10–4 to 8.1 × 10–4 lung cancer deaths per person per WLM.

Inhalation Risks to Subpopulations, Including Children

The NAS Radon in Drinking Water committee concluded that, except for the lung-cancer risk to smokers, there is insufficient information to permit quantitative evaluation of radon risks to susceptible sub-populations such as infants, children, pregnant women, elderly and seriously ill persons.

The BEIR VI committee (NAS 1999a) noted that there is only one study (tin miners in China) that provides data on whether risks from radon progeny are different for children, adolescents, and adults. Based on this study, the committee concluded that there was no clear indication of an effect of age at exposure, and the committee made no adjustments in the lung cancer risk model for exposures received at early ages.

(e) Unit Risk for Ingestion Exposure. The calculation of the unit risk from ingestion of radon in water depends on three key variables: (1) The amount of radon-containing water ingested, (2) the fraction of radon lost from the water before ingestion, and (3) the risk to the tissues per unit of radon absorbed into the body (risk coefficient). The values utilized by NAS for each of these factors are summarized next.

Water Ingestion Rate

EPA (USEPA 1993b, 1995) performed a review of available data on the amount of water ingested by residents. In brief, water ingestion can be divided into two categories: direct tap water (that which is ingested as soon as it is taken from the tap) and indirect tap water (water used in cooking, for making coffee, *etc.*). Available data indicate nearly all radon is lost from indirect tap water before ingestion, so only direct tap water is of concern. Based on available data (Pennington 1983; USEPA 1984; Ershow and Cantor 1989, USEPA 1993b, USEPA 1995) scientists estimated that the mean of the direct tap water ingestion rate was 0.65 liters per day (L/day), with a credible range of about 0.57 to 0.74 L/day. Based mainly on this analysis, NAS (1999b) identified 0.6 L/day as the best estimate of direct tap water intake, and utilized this value in the calculation of the unit risk from radon ingestion. This value includes direct tap water ingested at all locations, and so includes both residential and non-residential exposures.

The analysis conducted for radon in drinking water uses radon-specific estimates of water consumption, based on guidance from the NAS Radon in Drinking Water committee. Based on radon's unique characteristics, this approach is different from the Agency's approach to other drinking water contaminants.

In general, in calculating the risk for all other water contaminants, EPA uses 2 liters per day as the average amount of water consumed by an individual. For radon, the Agency used 0.6 liters per day to estimate the risks of radon ingestion. The NAS ingestion risk number is derived from an average risk/radiation coefficient, an average drinking water ingestion rate, and an average life expectancy. NAS chose to use an ingestion rate of 0.6 liter per day, based on an assumption that only 0.6 liters of the ''direct'' water will retain radon. Since radon is very readily released during normal household water use, we assume that radon in water used for indirect purposes (cooking, making coffee, etc) is released before drinking. Only direct water (drinking from tap directly) is used to estimate ingestion risk.

The Agency solicits comments on this approach to estimating the ingestion risk of radon in drinking water, particularly the assumption of 0.6 liters per day direct consumption.

Fraction of Radon Remaining During Water Transfer From the Tap

Because radon is a gas, it tends to volatilize from water as soon as the water is discharged from the plumbing system into any open container or utensil. As would be expected, the fraction of radon volatilized before consumption depends on time, temperature, surface area-to-volume ratio, and degree of mixing or aeration. A previous analysis by EPA (USEPA 1995) identified a value of 0.8 as a reasonable estimate of the mean fraction remaining before ingestion, with an estimated credibility interval about the mean of 0.7 to 0.9. Because data are so sparse, and in order to be conservative, NAS assumed a point estimate of 1.0 for this factor (NAS 1999b).

Risk per Unit of Radon Absorbed (Risk Coefficient)

The NAS Radon in Drinking Water committee reviewed a number of publications on the risk from ingestion of radon, and noted that there was a wide range in the estimates, due mainly to differences and uncertainties in the way radon is assumed to be absorbed across the gastrointestinal tract. Therefore, the committee developed new mathematical models of the diffusion of radon in the stomach and the behavior of radon dissolved in blood and other tissues to calculate the radiation dose absorbed by tissues following ingestion of radon dissolved in water (NAS 1999b).

NAS determined that the stomach wall has the largest exposure (and hence the largest risk of cancer) following oral exposure to radon in water, but that there is substantial uncertainty on the rate and extent of radon entry into the wall of the stomach from the stomach contents. The ''base case'' used by NAS assumed that diffusion of radon from the stomach contents occurs through a surface mucus layer and a layer of non-radiosensitive epithelial cells before coming into proximity with the radiosensitive stem cells. Below this layer, diffusion into capillaries was assumed to remove radon and reduce the concentration to zero. Based on this model, the concentration of radon near the stem cells was about 30 percent of that in the stomach contents.

The distribution of absorbed radon to peripheral tissues was estimated by NAS using a physiologically-based pharmacokinetic (PBPK) model based on the blood flow model of Leggett and Williams (1995). The committee's analysis considered that each radioactive decay product formed from radon decay in the body exhibited its own behavior with respect to tissues of deposition, retention, and routes of excretion with the ICRP's age-specific biokinetic models The computational method used by the NAS Radon in Drinking Water committee to calculate the age-and gender-averaged cancer death risk from lifetime ingestion of radon is described in EPA's Federal Guidance Report 13 (USEPA 1998d).

Results: Ingestion Unit Risk

The NAS Radon in Drinking Water committee estimated that an age- and gender-averaged cancer death risk from lifetime ingestion of radon dissolved in drinking water at a concentration of 1 Bq/L probably lies between 3.8×10^{-7} and 4.4×10^{-6}, with 1.9×10^{-6} as the best central value. This is equivalent to a lifetime risk of 7.0×10^{-8} per pCi/L, with a credible range of 1.4×10^{-8} to 1.6×10^{-7} per pCi/L. This uncertainty range is based mainly on uncertainty in the estimated dose to the stomach and in the epidemiologic data used to estimate the risk (NAS 1999b), and does not include the uncertainty in exposure factors such as average daily direct tap water ingestion rates or radon loss before ingestion. The lifetime risk estimate of 7.0×10^{-8} per pCi/L corresponds to an ingestion risk coefficient of 4.29×10^{-12} per pCi ingested.

Ingestion Risk to Children

NAS (1999b) performed an analysis to investigate the relative contribution of radon ingestion at different ages to the total risk. This analysis considered the age dependence of: radon consumption, behavior of radon and its decay products in the body, organ size, and risk. The results indicated that even though water intake rates are lower in children than in adults, dose coefficients are higher in children because of their smaller body size. In addition, the cancer risk coefficient for ingested radon is greater for children than for adults. Based on dose and stomach cancer risk models, NAS (1999b) estimated that about 30% of lifetime ingestion risk was due to exposures occurring during the first 10 years of life. However, the NAS found no direct epidemiological evidence to suggest that any sub-population is at increased risk from ingestion of radon. In addition, ingestion risk as a whole accounts for only 11% of total risk from radon exposure from drinking water for the general population, with inhalation accounting for the remaining 89%. The NAS did not identify children, or any other groups except smokers, as being at significantly higher overall risk from exposure to radon in drinking water.

(f) Summary of NAS Lifetime Unit Risk Estimates. Table XII.4 summarizes the lifetime average unit risk estimates derived by the NAS Radon in Drinking Water committee.

TABLE XII.4.—NAS RADON IN DRINKING WATER COMMITTEE ESTIMATE OF LIFETIME UNIT RISK POSED BY EXPOSURE TO RADON IN DRINKING WATER

Exposure route	Smoking status	Gender-averaged lifetime unit risk	
		Risk per Bq/L in water	Risk per pCi/L in water
Inhalation	Ever	2.6×10^{-5}	9.6×10^{-7}
	Never	0.50×10^{-5}	1.9×10^{-7}
	All	1.6×10^{-5}	5.9×10^{-7}
Ingestion	All	0.19×10^{-5}	7.0×10^{-8}
Total Risk (inhalation + ingestion)	All	1.8×10^{-5}	6.6×10^{-7}

(g) Other Health Effects. The NAS Radon in Drinking Water committee was asked to review teratogenic and reproductive risks from radon. The committee concluded there is no scientific evidence of teratogenic and reproductive risks associated with either inhalation or ingestion of radon.

(h) Relative Magnitude of the Risk from Radon in Water. The NAS Radon in Drinking Water committee concluded that radon in water typically adds only a small increment to the indoor air concentration. The committee estimated the cancer deaths per year due to radon in indoor air (total), radon in outdoor air, radon progeny from waterborne radon, and ingestion of radon in water are 18, 200, 720, 160, and 23, respectively. However, the committee recognized that radon in water is the largest source of cancer risk in drinking water compared to other regulated chemicals in water.

D. Estimated Individual and Population Risks

Based on the findings and recommendations of the NAS Radon in Drinking Water committee, EPA has performed a re-evaluation of the risks posed by radon in water (USEPA 1999b). This assessment relied upon the inhalation and ingestion unit risks derived by NAS (1999b), and calculated risks to individuals and the population by combining the unit risks derived by NAS with the latest available data on the occurrence of radon in public water systems (USEPA 1999g).

In brief, the risk to a person from exposure to radon in water is calculated by multiplying the concentration of radon in the water (pCi/L) by the unit risk factor (risk per pCi/L) for the exposure pathway of concern (ingestion, inhalation). The population risk (the total number of fatal cancer cases per year in the United States due to radon ingestion in water) is estimated by multiplying the average annual individual risk (cases per person per year) by the total number of people exposed. Data which EPA used to calculate individual risks and population risks are summarized next.

Radon Concentration in Community Water Systems

The EPA has recently completed a detailed review and evaluation of the latest available data on the occurrence of radon in community water systems (USEPA 1999g; see Section XI). In brief, the concentration of radon in drinking water from surface water sources is very low, and exposures from surface water systems can generally be ignored. However, radon does occur in most groundwater systems, with the concentration values tending to be highest in areas where groundwater is in contact with granite. In addition, radon concentrations tend to vary as a function of the size of the water system, being somewhat higher in small systems than in large systems (USEPA 1999g). Based on EPA's analysis, the population-weighted average concentration of radon in community ground water systems is estimated to be 213 pCi/L, with a credible range of about 190 to 240 pCi/L (USEPA 1999g).

Total Exposed Population

Based on data available from the Safe Drinking Water Information System (SDWIS), EPA estimates that 88.1 million people (about one-third of the population of the United States) are served in their residence by community water supply systems using ground water (USEPA 1998a).

Based on these data on radon occurrence and size of the exposed population, EPA calculated the risks from water-borne radon to people exposed at residences served by community groundwater systems. EPA also calculated revised quantitative uncertainty analysis of the risk estimates at residential locations, incorporating NAS estimates of the uncertainty inherent in the unit risks for each pathway. In addition, EPA performed screening level estimates of risk to people exposed to water-borne radon in various types of non-residential setting. EPA's findings are summarized next.

1. Risk Estimates for Ingestion of Radon in Drinking Water

Table XII.5 presents EPA's estimate of the mean individual risk (fatal cancer cases per person per year) for the people who ingest water from community ground water systems. This includes exposures that occur both in the residence and in non-residential settings (the workplace, restaurants, etc). The lower and upper bounds around the best estimate were estimated using Monte Carlo simulation techniques (USEPA 1999b).

TABLE XII.5.—ESTIMATED RISK FROM RADON INGESTION AT RESIDENTIAL AND NON-RESIDENTIAL LOCATIONS SERVED BY COMMUNITY WATER SYSTEMS

Parameter	Lower bound	Best estimate	Upper bound
Mean Annual Individual Risk (cancer deaths per person per year)	3.2×10^{-8}	2.0×10^{-7}	4.3×10^{-7}
Population Risk (cancer deaths per year)	3	18	38

2. Risk Estimates for Inhalation of Radon Progeny Derived From Waterborne Radon

(a) Inhalation Exposure to Radon Progeny in the Residential Environment. Table XII.6 presents the EPA's best estimate of the mean individual risk and population risk of lung cancer fatality due to inhalation of radon progeny derived from water-borne radon at residences served by community groundwater systems. Lower and upper bounds on the individual and population risk estimates were derived using Monte Carlo simulation techniques.

TABLE XII.6.—ESTIMATED RISKS FROM INHALATION OF WATER-BORNE RADON PROGENY IN RESIDENCES SERVED BY COMMUNITY GROUND WATER SUPPLY SYSTEMS

Parameter	Lower bound	Best estimate	Upper bound
Mean Annual Individual Risk (lung cancer deaths per person per year)	7.9×10^{-7}	1.7×10^{-6}	3.0×10^{-6}
Population Risk (lung cancer deaths per year)	70	148	263

Of the total number of lung cancer deaths due to water-borne radon, most (about 84 percent) are expected to occur in ever-smokers, with the remainder (about 16 percent) occurring in never-smokers.

Analysis of Peak Exposures and Risks Due to Showering

Both NAS and EPA have paid special attention to the potential hazards associated with high exposures to radon that may occur during showering. High exposure occurs during showering because a large volume of water is used, release of radon from shower water is nearly complete, and the radon enters a fairly small room (the shower/bathroom). However, both NAS (1999b) and USEPA (1993b, 1995) concluded that the risk to humans from radon released during showering was likely to be small. This is because the inhalation risk from radon is due almost entirely to radon progeny and not to radon gas itself, and it takes time (several hours) for the radon progeny to build up from the decay of the radon gas released from the water. For example, in a typical shower scenario (about 10 minutes), the level of progeny builds up to only 2 to 4 percent of its maximum possible value. Thus, showering is one of many indoor water uses that contribute to the occurrence of radon in indoor air, but hazards from inhalation of radon during showering are not of special concern.

(b) Inhalation Exposure to Radon Progeny in the Non-Residential Environment. The results summarized to this point relate to exposures which occur in homes. However, on average, people spend about 30 percent of their time at other locations. Surveys of human activity patterns reveal that time outdoors or in cars accounts for about 13 percent of the time (USEPA 1996), and about 17 percent of the time, on average across the entire population (including both workers and non-workers), is spent in non-residential structures. Such non-residential buildings are presumably all served with water, so exposure to radon and radon progeny is expected to occur, at least in buildings served by groundwater. Because data needed to quantify exposure at non-residential locations are limited, EPA has performed only a screening

level evaluation to date. This evaluation may be revised in the future, depending on the availability of more detailed and appropriate input data.

As with exposures in the home, the largest source of exposure and risk from water-borne radon in non-residential buildings is inhalation of radon progeny. Limited data were found on measured transfer factors in non-residential buildings, so values were estimated for several different types of buildings based on available data on water use rates, building size, and ventilation rate, based on the following basic equation:

$$TF = (W \bullet e)/(V \bullet \lambda)$$

Where:

W = Water use (L/person/day)
e = Use-weighted fractional release of radon from water to air
V = Building volume (L/person)
λ = Ventilation rate (air changes/day)

The resulting transfer factor values varied as a function of building type, based on limited data, but the average across all building types was about 1×10^{-4} (the same as for residences). Very few data were located for the equilibrium factor in non-residential buildings, so a value of 0.4 (the same as in a residence) was assumed (USEPA 1999b).

Based on an estimated average transfer factor of 1×10^{-4} and assuming an average occupancy factor of 17 percent at non-residential locations, the estimated lifetime and annual risks of death from lung cancer due to exposure per unit concentration of radon (1pCi/L) in water are 1.4×10^{-7} per pCi/L and 1.9×10^{-9} per pCi/L, respectively.

Assuming a mean radon concentration in water of 213 pCi/L, these unit risks correspond to lifetime and annual individual risks of 3.1×10^{-5} and 4.1×10^{-7} lung cancer deaths per person. Assuming the same population size of 88.1 million population exposed to radon through community ground water supplies, EPA's best estimate of the number of fatal cancer cases per year resulting from the inhalation of radon progeny in non-residential environments is 36 lung cancer deaths per year (USEPA 1999b) (from the population of individuals exposed in non-residential settings served by community ground water supplies).

(c) Analysis of Risk Associated with Exposure at NTNC Locations. A subset of the water systems serving non-residential populations are the non-transient non-community (NTNC) systems. Statistics from SDWIS indicate there are about 5.2 million individuals exposed at buildings served by NTNC groundwater systems (USEPA 1999b).

Data on radon exposures at locations served by NTNC systems are limited. However, data are available for water used and population size at each of 40 strata of NTNC systems (USEPA 1998a). Assuming (a) the exposure at NTNC locations is occupational in nature with about 8 hr/day, 250 days/yr, and 25 years per lifetime for workers and 8 hr/day, 180 days/yr, and 12 years per lifetime for students, (b) the same transfer factor (1×10^{-4}) and equilibrium factor (0.4) assumed for other non-residential buildings apply at NTNC locations, and (c) the concentration of radon in water at NTNC locations is about 60 percent higher than in community water systems (mean concentration = 341 pCi/L) (see Section XI of this preamble), then the estimated population-weighted average individual annual and lifetime lung cancer risks are 2.6×10^{-7} and 2.0×10^{-5}, respectively.

3. Risk Estimates for Inhaling Radon Gas

NAS (1999b) did not derive a unit risk factor for inhalation of radon gas, but provided in their report a set of annual effective doses to tissues (liver, kidney, spleen, red bone marrow, bone surfaces, other tissues) from continuous exposure to 1Bq/m^3 of radon in air. These doses to internal organs from the decay of radon gas absorbed across the lung and transported to internal sites were based on calculations by Jacobi and Eisfeld (1980). Based on these dose estimates, EPA estimated a unit risk value using an approach similar to that used by NAS to derive the unit risk for ingestion of radon gas in water. The organ-specific doses reported by Jacobi and Eisfeld were multiplied by the lifetime-average organ-specific and gender-specific risk coefficients (risk of fatal cancer per rad) from Federal Guidance Report No. 13 (USEPA 1998d). Based on an average transfer factor of 1×10^{-4}, and assuming 70 percent occupancy, the estimated annual average unit risk is 8.5×10^{-11} cancer deaths per pCi/L in water. This corresponds to a lifetime average unit risk of 6.3×10^{-9} per pCi/L. This unit risk excludes the risk of lung cancer from inhaled radon gas, since this risk is already included in the unit risk from radon progeny. Based on the population-weighted average radon concentration of 213 pCi/L, the lifetime average individual risk is 1.35×10^{-6} cancer deaths per person, and the average annual individual risk is 1.8×10^{-8} cancer deaths per person per year. Based on an exposed population of 88.1 million people, the annual population risk is about 1.6 cancer deaths/year. The uncertainty range around this estimate, derived using Monte Carlo simulation techniques, is about 1.0 to 2.7 cancer deaths per year (USEPA 1999b).

4. Combined Fatal Cancer Risk

The best estimates of fatal cancer risks to residents from ingesting radon in water, inhalation of waterborne progeny, and inhalation of radon gas are presented in Table XII.7. As seen, EPA estimates that an individual's combined fatal cancer risk from lifetime residential exposure to drinking water containing 1 pCi/L of radon is slightly less than 7 chances in 10 million (7×10^{-7}), and that the population risk is about 168 cancer deaths per year (uncertainty range = 80 to 288 per year). Of this risk, most (88 percent) is due to inhalation of radon progeny, with 11 percent due to ingestion of radon gas, and less than 1 percent due to inhalation of radon gas.

TABLE XII.7.—SUMMARY OF UNIT RISK, INDIVIDUAL RISK AND POPULATION RISK ESTIMATES FOR RESIDENTIAL EXPOSURE TO RADON IN COMMUNITY GROUNDWATER SUPPLIES

Exposure pathway	Lifetime unit risk (fatal cancer cases per person per pCi/L)	Annual individual risk (fatal cancer cases per person per year)	Annual population risk (fatal cancer cases per year)
Radon Gas Ingestion	7.0×10^{-8}	2.0×10^{-7}	18
Radon Progeny Inhalation	5.9×10^{-7}	1.7×10^{-6}	148

TABLE XII.7.—SUMMARY OF UNIT RISK, INDIVIDUAL RISK AND POPULATION RISK ESTIMATES FOR RESIDENTIAL EXPOSURE TO RADON IN COMMUNITY GROUNDWATER SUPPLIES—Continued

Exposure pathway	Lifetime unit risk (fatal cancer cases per person per pCi/L)	Annual individual risk (fatal cancer cases per person per year)	Annual population risk (fatal cancer cases per year)
Radon Gas Inhalation	6.3×10^{-9}	1.8×10^{-8}	1.6
Total (credible bounds)	6.7×10^{-7} (3.6×10^{-7} – 9.7×10^{-7})	1.9×10^{-6} (0.9×10^{-6} – 3.3×10^{-6})	168 (80 – 288)

EPA believes that radon in community groundwater water systems also contributes exposure and risk to people when they are outside the residence (e.g., at school, work, etc.). Although data are limited, a screening level estimate suggests that this type of exposure could be associated with about 36 additional lung cancer deaths per year.

Request for Comment

EPA solicits public comments on its assessment of risk from radon in drinking water. In particular, EPA requests comment and recommendations on the best data sources and best approaches to use for evaluating ingestion and inhalation exposures that occur for members of the public (including both workers and non-workers) at non-residential buildings (e.g. restaurants, churches, schools, offices, factories, etc).

E. Assessment by National Academy of Sciences: Multimedia Approach to Risk Reduction

The NAS report, ''Risk Assessment of Radon in Drinking Water,'' summarized several assessments of possible approaches relating reduction of radon in indoor air from soil gas to reduction of radon in drinking water. The NAS Report provided useful perspectives on multimedia mitigation issues that EPA used in developing the proposed criteria and guidance for multimedia mitigation programs. The NAS Committee focused on how the multimedia approach might be applied at the community level and defined a series of scenarios, assuming that multimedia programs would be implemented by public water systems. The report may provide useful perspectives of interest to public water systems if their State does not develop an EPA-approved MMM program.

For most of the scenarios, the Committee chose primarily to focus on how to compare the risks posed by radon in indoor air from soil gas to the risks from radon in drinking water in a home in a local community. They assessed the feasibility of different activities based on costs, radon concentrations, different assumptions about risk reduction actions that might be taken, and other factors.

Overall, the Committee suggested that reduction of indoor radon can be an alternative and more effective means of reducing the overall risk from radon. They went on to conclude that mitigation of airborne radon to achieve equal or greater radon risk reduction ''makes good sense from a public health perspective.'' They also noted that non-economic issues, such as equity concerns, could factor into a community's decision whether to undertake a multimedia mitigation program.

The Committee also discussed the role of various indoor air mitigation program strategies, or ''mitigation measures'' as they are described in SDWA. The Committee concluded that an education and outreach program is important to the success of indoor radon risk reduction programs, but would not in and of itself be sufficient to claim that risk reduction took place. Based on an assessment of several State indoor radon programs, they found that States with effective programs had several factors in common in the implementation of their programs. They concluded that the effectiveness of these State programs were the result of: (1) Promoting wide-spread testing of homes, (2) conducting radon awareness campaigns, (3) providing public education on mitigation, and (4) ensuring the availability of qualified contractors to test and mitigate homes.

These views are consistent with the examples of indoor radon activities that Congress set forth in the radon provision in SDWA on which State Multimedia Mitigation programs may rely. These include ''public education, testing, training, technical assistance, remediation grants and loans and incentive programs, or other regulatory or non-regulatory measures.'' These measures also represent many of the same strategies that are integral to the current national and State radon programs, as well as those outlined in the 1988 Indoor Radon Abatement Act, sections 304 to 307 (15 U.S.C. 2664–2667).

EPA recognizes, as does the National Academy of Sciences, that these activities and strategies are important to achieving public awareness and action to reduce radon, but that these actions are not in and of themselves actual risk reduction. Therefore, EPA has determined that State MMM plans will need to set and track actual risk reduction goals. However, the criteria and guidance for States to use in designing MMM program plans provides extensive flexibility in choosing strategies that reflect the needs of individual States.

The Committee discussed the effectiveness of various indoor radon control technologies and recommended that active sub-slab depressurization techniques are most effective for controlling radon in the mitigation of elevated radon levels in existing buildings and in the prevention of elevated levels in new buildings. (Active systems rely on mechanically-driven techniques (powered fans) to create a pressure gradient between the soil and building interior and thus, prevent radon entry.) The Committee expressed concern over the adequacy of the scientific basis for ensuring that such methods can be used reliably as a consistent outcome of normal design and construction methods. The Committee also noted the limited amount of data available to quantify the reduction in indoor radon levels expected when such techniques were used.

The Committee found that much of the comparative data available on the impact of the passive radon-resistant new construction features is confined to the impact of the passive thermal stack on radon levels and not on the other features of the passive radon-resistant new construction system, such as eliminating leakage paths, sealing utility penetrations, and prescribing the extent and quality of aggregate beneath the foundation. The Committee found that the passive stack alone yielded reductions in radon levels as great as 90%, that reductions in radon levels of about 40% are more typical, and that the effect of the passive stack may be considerably less in slab-on-grade houses that in houses with basements. However, the Committee also stated that the other features in the passive radon-resistant new construction system contribute to reducing radon levels. EPA notes that there are substantial difficulties in gathering good comparative data on these other features because of the significant variability of radon potential across building sites, even within a small area. In addition it is impractical to test the same house with and without radon resistant features. However, based on the Committee's discussion of the contributions of these other features to reducing radon levels, it is reasonable to expect that passive systems as a whole achieve greater reductions in radon than the passive stack alone.

EPA agrees with the Committee's perspective that active radon-reduction systems, while slightly more expensive, assure the greatest risk reduction in not only the mitigation of existing homes, but also in the construction of new homes. EPA also agrees with the Committee's perspective that more data on passive new construction systems would allow for more precise estimation of average expected reductions in radon levels in new homes from application of passive radon-resistant new construction techniques. However, EPA believes there is sufficient data and application experience to have a reasonable assurance that the passive techniques when used in new homes reduce indoor radon levels by about 50% on average. Further, these techniques have been adopted by the home construction industry into national model building codes and by many State and local jurisdictions into their building codes. EPA recommends that new homes built with passive radon-resistant new construction features be tested after occupancy and if elevated levels still exist, the passive systems be converted to active ones. For these reasons, EPA believes it is appropriate to consider passive radon-resistant new construction techniques for new homes as one means of achieving risk reduction through new construction in multimedia mitigation programs.

Economics and Impacts Analysis

XIII. What Is the EPA's Estimate of National Economic Impacts and Benefits?

A. Safe Drinking Water Act (SDWA) Requirements for the HRRCA

Section 1412(b)(13)(C) of the SDWA, as amended, requires EPA to prepare a Health Risk Reduction and Cost Analysis (HRRCA) to be used to support the development of the radon NPDWR. EPA was to publish the HRRCA for public comment and respond to significant comments in this preamble. EPA published the HRRCA in the **Federal Register** on February 26, 1999 (64 FR 9559). Responses to significant comments on the HRRCA are provided in Section XIII.H.

The HRRCA addresses the requirements established in Section 1412(b)(3)(C) of the amended SDWA, namely: (1) Quantifiable and non-quantifiable health risk reduction benefits for which there is a factual basis in the rulemaking record to conclude that such benefits are likely to occur as the result of treatment to comply with each level; (2) quantifiable and non-quantifiable health risk reduction benefits for which there is a factual basis in the rulemaking record to conclude that such benefits are likely to occur from reductions in co-occurring contaminants that may be attributed solely to compliance with the MCL, excluding benefits resulting from compliance with other proposed or promulgated regulations; (3) quantifiable and non-quantifiable costs for which there is a factual basis in the rulemaking record to conclude that such costs are likely to occur solely as a result of compliance with the MCL, including monitoring, treatment, and other costs, and excluding costs resulting from compliance with other proposed or promulgated regulations; (4) the incremental costs and benefits associated with each alternative MCL considered; (5) the effects of the contaminant on the general population and on groups within the general population, such as infants, children, pregnant women, the elderly, individuals with a history of serious illness, or other subpopulations that are identified as likely to be at greater risk of adverse health effects due to exposure to contaminants in drinking water than the general population; (6) any increased health risk that may occur as the result of compliance, including risks associated with co-occurring contaminants; and (7) other relevant factors, including the quality and extent of the information, the uncertainties in the analysis, and factors with respect to the degree and nature of the risk.

The HRRCA discusses the costs and benefits associated with a variety of radon levels. Summary tables and figures are presented that characterize aggregate costs and benefits, impacts on affected entities, and tradeoffs between risk reduction and compliance costs. The HRRCA serves as a foundation for the Regulatory Impact Analysis (RIA) for this proposed rule.

B. Regulatory Impact Analysis and Revised Health Risk Reduction and Cost Analysis (HRRCA) for Radon

Under Executive Order 12866, Regulatory Planning and Review, EPA must estimate the costs and benefits of the proposed radon rule in a Regulatory Impact Analysis (RIA) and submit the analysis to the Office of Management and Budget (OMB) in conjunction with the proposed rule. To comply with the requirements of E.O. 12866, EPA has prepared an RIA, a copy of which is available in the public docket for this proposed rulemaking. The revised HRRCA is now included as part of the RIA (USEPA 1999f). This section provides a summary of the information from the RIA for the proposed radon rule.

1. Background: Radon Health Risks, Occurrence, and Regulatory History

Radon is a naturally occurring volatile gas formed from the normal radioactive decay of uranium. It is colorless, odorless, tasteless, chemically inert, and radioactive. Uranium is present in small amounts in most rocks and soil, where it decays to other products including radium, then to radon. Some of the radon moves through air or water-filled pores in the soil to the soil surface and enters the air, and can enter buildings through cracks and other holes in the foundation. Some radon remains below the surface and dissolves in ground water (water that collects and flows under the ground's surface). Due to their very long half-life (the time required for half of a given amount of a radionuclide to decay), uranium and radium persist in rock and soil.

Exposure to radon and its progeny is believed to be associated with increased risks of several kinds of cancer. When radon or its progeny are inhaled, lung cancer accounts for most of the total incremental cancer risk. Ingestion of radon in water is suspected of being associated with increased risk of tumors of several internal organs, primarily the stomach. As required by the SDWA, as amended, EPA arranged for the National Academy of Sciences (NAS) to assess the health risks of radon in drinking water. The NAS released the pre-publication draft of the ''Report on the Risks of Radon in Drinking Water,'' (NAS Report) in September 1998 and published the Report in July 1999 (NAS 1999b). The analysis in this RIA uses information from the 1999 NAS Report (see Section XII.C of this preamble). The NAS Report represents a comprehensive assessment of scientific data gathered to date on radon in drinking water. The report, in general, confirms earlier EPA scientific conclusions and analyses of radon in drinking water.

NAS estimated individual lifetime unit fatal cancer risks associated with exposure to radon from domestic water use for ingestion and inhalation pathways (Table XIII.1). The results show that inhalation of radon progeny accounts for most (approximately 88 percent) of the individual risk associated with domestic water use, with almost all of the remainder (11 percent) resulting from directly ingesting radon in drinking water. Inhalation of radon progeny is associated primarily with increased risk of lung cancer, while ingestion exposure is associated primarily with elevated risk of stomach cancer.

TABLE XIII.1.—ESTIMATED RADON UNIT LIFETIME FATAL CANCER RISKS IN COMMUNITY WATER SYSTEMS

Exposure pathway	Cancer unit risk per pCi/L in water	Proportion of total risk (percent)
Inhalation of radon progeny[1]	5.9×10^{-7}	88
Ingestion of radon[1]	7.0×10^{-8}	11
Inhalation of radon gas[2]	6.3×10^{-9}	1
Total	6.7×10^{-7}	100

[1] Source: NAS 1998B.
[2] Source: Calculated by EPA from radiation dosimetry data and risk coefficients provided by NAS (NAS 1998B).

The NAS Report confirmed that indoor air contamination arising from soil gas typically accounts for the bulk of total individual risk due to radon exposure. Usually, most radon gas enters indoor air by diffusion from soils through basement walls or foundation cracks or openings. Radon in domestic water generally contributes a small proportion of the total radon in indoor air.

The NAS Report is one of the most important inputs used by EPA in the RIA. EPA has used the NAS's assessment of the cancer risks from radon in drinking water to estimate both the health risks posed by existing levels of radon in drinking water and also the cancer deaths prevented by reducing radon levels.

In updating key analyses and developing the framework for the cost-benefit analysis presented in the RIA, EPA has consulted with a broad range of stakeholders and technical experts. Participants in a series of stakeholder meetings held in 1997, 1998, and 1999 included representatives of public water systems, State drinking water and indoor air programs, Tribal water utilities and governments, environmental and public health groups, and other Federal agencies.

The RIA builds on several technical components, including estimates of radon occurrence in drinking water, analytical methods for detecting and measuring radon levels, and treatment technologies. Extensive analyses of these issues were undertaken by the Agency in the course of previous rulemaking efforts for radon and other radionuclides. Using data provided by stakeholders, and from published literature, the EPA has updated these technical analyses to take into account the best currently available information and to respond to comments on the 1991 proposed NPDWR for radon.

The analysis presented in the RIA uses updated estimates of the number of active public drinking water systems obtained from EPA's Safe Drinking Water Information System (SDWIS). Treatment costs for the removal of radon from drinking water have also been updated. The RIA follows current EPA policies with regard to the methods and assumptions used in cost and benefit assessment.

As part of the regulatory development process, EPA has updated and refined its analysis of radon occurrence patterns in ground water supplies in the United States (USEPA 1998l). This new analysis incorporates information from the EPA's 1985 National Inorganic and Radionuclides Survey (NIRS) of approximately 1000 community ground water systems throughout the United States, along with supplemental data provided by the States, water utilities, and academic research. The new study also addressed a number of issues raised by public comments in the previous occurrence analysis that accompanied the 1991 proposed NPDWR, including characterization of regional and temporal variability in radon levels, and the impact of sampling point for monitoring compliance.

In general, radon levels in ground water in the United States have been found to be the highest in New England and the Appalachian uplands of the Middle Atlantic and Southeastern States. There are also isolated areas in the Rocky Mountains, California, Texas, and the upper Midwest where radon levels in ground water tend to be higher than the United States average. The lowest ground water radon levels tend to be found in the Mississippi Valley, lower Midwest, and Plains States. When comparing radon levels in ground water to radon levels in indoor air at the States level, the distributions of radon concentrations in indoor air do not always mirror distributions of radon in ground water.

2. Consideration of Regulatory Alternatives

(a) Regulatory Approaches. The RIA evaluates MCL options for radon in ground water supplies of 100, 300, 500, 700, 1000, 2000, and 4000 pCi/L. As Table VII.1 in Section VII of the preamble illustrates, the costs and benefits increase as the radon level decreases and the benefit-cost ratios are very similar at each level. The RIA also presents information on the costs and benefits of implementing multimedia mitigation (MMM) programs. The scenarios evaluated are described in detail in Sections 9 and 10 of the RIA (USEPA 1999f). Based on the analysis shown in the report, the selected regulatory alternative discussed next has a significant multimedia mitigation component. For more information on this analysis, please refer to the RIA.

(b) Selected Regulatory Alternatives. A CWS must monitor for radon in drinking water in accordance with the regulations, as described in Section VIII of this preamble, and report their results to the State. If the State determines that

the system is in compliance with the MCL of 300 pCi/L, the CWS does not need to implement a MMM program (in the absence of a State program), but must continue to monitor as required.

As discussed in Section VI, EPA anticipates that most States will choose to develop a State-wide MMM program as the most cost-effective approach to radon risk reduction. In this case, all CWSs within the State may comply with the AMCL of 4000 pCi/L. Thus, EPA expects the vast majority of CWSs will be subject only to the AMCL. In those instances where the State does not adopt this approach, the proposed regulation provides the following requirements:

(i) Requirements for Small Systems Serving 10,000 People or Less. The EPA is proposing that small CWSs serving 10,000 people or less must comply with the AMCL, and implement a MMM program (if there is no state MMM program). This is the cut-off level specified by Congress in the 1996 Amendments to the Safe Drinking Water Act for small system flexibility provisions. Because this definition does not correspond to the definitions of ''small'' for small businesses, governments, and non-profit organizations previously established under the RFA, EPA requested comment on an alternative definition of ''small entity'' in the preamble to the proposed Consumer Confidence Report (CCR) regulation (63 FR 7620, February 13, 1998). Comments showed that stakeholders support the proposed alternative definition. EPA also consulted with the SBA Office of Advocacy on the definition as it relates to small business analysis. In the preamble to the final CCR regulation (63 FR 4511, August 19, 1998), EPA stated its intent to establish this alternative definition for regulatory flexibility assessments under the RFA for all drinking water regulations and has thus used it for this radon in drinking water rulemaking. Further information supporting this certification is available in the public docket for this rule.

EPA's regulation expectation for small CWSs is the MMM and AMCL because this approach is a much more cost-effective way to reduce radon risk than compliance with the MCL. (While EPA believes that the MMM approach is preferable for small systems in a non-MMM State, they may, at their discretion, choose the option of meeting the MCL of 300 pCi/L instead of developing a local MMM program). The CWSs will be required to submit MMM program plans to their State for approval. (See Sections VI.A and F for further discussion of this approach).

SDWA Section 1412(b)(13)(E) directs EPA to take into account the costs and benefits of programs to reduce radon in indoor air when setting the MCL. In this regard, the Agency expects that implementation of a MMM program and CWS compliance with 4000 pCi/L will provide greater risk reduction for indoor radon at costs more proportionate to the benefits and commensurate with the resources of small CWSs. It is EPA's intent to minimize economic impacts on a significant number of small CWSs, while providing increased public health protection by emphasizing the more cost-effective multimedia approach for radon risk reduction.

(ii) Requirements for Large Systems Serving More Than 10,000 People. The proposal requires large community water systems, those serving populations greater than 10,000, to comply with the MCL of 300 pCi/L unless the State develops a State-wide MMM program, or the CWS develops and implements a MMM program meeting the four regulatory requirements, in which case large systems may comply with the AMCL of 4,000pCi/L. CWSs developing their own MMM plans will be required to submit these plans to their State for approval.

(c) Background on the Selection of the MCL and AMCL. For a description of EPA's process in selecting the MCL and AMCL, see Section VII.D of today's preamble.

C. Baseline Analysis

Data and assumptions used in establishing baselines for the comparison of costs and benefits are presented in the next section. While the rule as proposed does not require 100 percent compliance with an MCL, an analysis of these full compliance scenarios are required by the SDWA, as amended, and were an important feature in the development of the NPDWR for radon.

1. Industry Profile

Radon is found at appreciable levels only in systems that obtain water from ground water sources. Thus, only ground water systems would be affected by the proposed rule. The following discussion addresses various characteristics of community ground water systems that were used in the assessment of regulatory costs and benefits. Table XIII.2 shows the estimated number of community ground water systems in the United States. This data originally came from EPA's Safe Drinking Water Information System (SDWIS) and are summarized in EPA's Drinking Water Baseline Handbook (USEPA, 1999c). EPA estimates that there were 43,908 community ground water systems active in December 1997 when the SDWIS data were evaluated. Approximately 96.5 percent of the systems serve fewer than 10,000 customers, and thus fit EPA's definition of a ''small'' system (see 63 FR 44512 at 44524–44525, August 19, 1998). Privately-owned systems comprise the bulk of the smaller size categories, whereas most larger systems are publicly owned.

TABLE XIII.2.—NUMBER OF COMMUNITY GROUND WATER SYSTEMS IN THE UNITED STATES [1]

Primary source/ ownership	System size category									
	25–100	101–500	501–1,000	1,001–3,301	3,301–10,000	10,001–50,000	50,001–100,000	100,001–1,000,000	>1,000,000	Total
Total	14,232	15,070	4,739	5,726	2,489	1,282	139	70	2	43,908
Public	1,202	4,104	2,574	3,792	1,916	997	113	52	2	14,764
Private	12,361	9,776	1,705	1,531	459	243	24	14	0	26,252
Purchased-Public	114	427	265	272	84	36	1	4	0	1,203
Purchased-Private	171	347	101	79	13	3	1	0	0	718
Other	384	416	94	52	17	3	0	0	0	971

[1] Source: USEPA 1999c.

In addition to the number of affected systems, the total number of sources (wells) is an important determinant of potential radon mitigation costs. Larger systems tend to have larger numbers of sources than small ones, and it has been conservatively assumed in the mitigation cost analysis that each source out of compliance with the MCL or AMCL would need to install control equipment.

Table XIII.3 summarizes the estimated number of wells per ground water system. Both the number of wells and the variability in the number of wells increases with the number of customers served. These characteristics of community ground water sources are included in the mitigation cost analysis discussed in Section 7 of the RIA (USEPA 1999f).

2. Baseline Assumptions

In addition to the characteristics of the ground water suppliers, other important ''baseline'' assumptions were made that affect the estimates of potential costs and benefits of radon mitigation. Two of the most important assumptions relate to the distribution of radon in ground water sources and the technologies that are currently in place for ground water systems to control radon and other pollutants.

As noted in Section 3 of the RIA (USEPA 1999f), EPA has recently completed an analysis of the occurrence patterns of radon in groundwater supplies in the United States (USEPA 1999g). This analysis used the NIRS and other data sources to estimate national distributions of groundwater radon levels in community systems of various sizes. The results of that analysis are summarized in Table XIII.4. These distributions are used to calculate baseline individual and population risks, and to predict the proportions of systems of various sizes that will require radon mitigation.

TABLE XIII.3.—ESTIMATED AVERAGE NUMBER OF WELLS PER GROUNDWATER SYSTEM [1]

	System size category							
	25–100	101–500	501–1,000	1001–3,301	3,301–10,000	10,001–50,000	50,001–100,000	100,001–1,000,000
Average Number of Wells (Confidence Interval)	1.5 (0.2)	2.0 (0.2)	2.3 (0.2)	3.1 (0.3)	4.6 (1.1)	9.8 (1.8)	16.1 (2.2)	49.9 (12.7)

[1] Source: USEPA 1999c.

TABLE XIII.4.—DISTRIBUTION OF RADON LEVELS IN U.S. GROUNDWATER SOURCES

Statistic	Population served				
	25–100	101–500	501–3,300	3,301–10,000	>10,000
Geometric Mean, pCi/L	312	259	122	124	132
Geometric Standard Deviation, pCi/L	3.04	3.31	3.22	2.29	2.31
Arithmetic Mean	578	528	240	175	187

The costs of radon mitigation are affected to some extent by the treatment technologies that are currently in place to mitigate radon and other pollutants, and by the existence of pre- and post-treatment technologies that affect the costs of mitigation. EPA has conducted an extensive analysis of water treatment technologies currently in use by ground-water systems. Table XIII.5 shows the proportions of ground water systems with specific technologies already in place, broken down by system size (population served). Many ground water systems currently employ disinfection, aeration, or iron/manganese removal technologies. This distribution of pre-existing technologies serves as the baseline against which water treatment costs are measured. For example, costs of disinfection are attributed to the radon rule only for the estimated proportion of systems that would have to install disinfection as a post-treatment because they do not already disinfect. The cost analysis assumes that any system affected by the rule will continue to employ pre-existing radon treatment technology and pre- and post-treatment technologies in their efforts to comply with the rule. Where pre- or post-treatment technologies are already in place it is assumed that compliance with the radon rule will not require any upgrade or change in the pre- or post-treatment technologies. Therefore, no incremental cost is attributed to pre- or post-treatment technologies. This may underestimate costs if pre- or post-treatment technologies need to be changed (e.g., a need for additional chlorination after the installation of packed tower aeration). The potential magnitude of this cost underestimation is not known, but is likely to be a very small fraction of total treatment costs.

Table XIII.5.—Estimated Proportions of Groundwater Systems With Water Treatment Technologies Already in Place (Percent) [1]

Water treatment technologies in place	System Size (Population Served)							
	25–100	101–500	501–1,000	1,001–3,300	3,301–10,000	10,001–50,000	50,001–100,000	100,001 1,000,000
Fe/Mn removal & aeration & disinfection	0.4	0.2	1.2	0.6	2.9	2.2	3.1	2
Fe/Mn removal & aeration	0	0.1	0.2	0.1	0.4	0.1	0.4	0.1
Fe/Mn removal & disinfection	2.1	5.1	8.3	3	7.8	7.4	9.7	6.8
Fe/Mn removal	1.9	1.5	1.5	1	1.1	0.4	1.1	0.2
Aeration & disinfection only	0.9	3.2	9.8	13.7	20.9	19.7	18.6	19.9
Aeration only	0.8	1	1.8	2.9	2.9	1	2.1	0.6
Disinfection only	49.6	68.2	65	65	56.3	66	58.3	68.3

Table XIII.5.—Estimated Proportions of Groundwater Systems With Water Treatment Technologies Already in Place (Percent) [1]—Continued

Water treatment technologies in place	System Size (Population Served)							
	25–100	101–500	501–1,000	1,001–3,300	3,301–10,000	10,001–50,000	50,001–100,000	100,001 1,000,000
None	44.3	20.7	12.2	13.7	7.7	3.2	6.7	2.1

[1]. Source: EPA analysis of data from the Community Water System Survey (CWSS), 1997, and Safe Drinking Water Information System (SDWIS), 1998.

The treatment baseline assumptions shown in Table XIII.5 were used in the initial analysis for the development of the NPDWR for radon. These assumptions were used to establish the costs of 100 percent compliance with an MCL. Another analysis, which portrays the costs of the rule as recommended in this proposed rulemaking, is provided in the results section of this summary and also in Section 9 of the RIA.

D. Benefits Analysis

11. Quantifiable and Non-Quantifiable Health Benefits

The quantifiable health benefits of reducing radon exposures in drinking water are attributable to the reduced incidence of fatal and non-fatal cancers, primarily of the lung and stomach. Table XIII.6 shows the health risk reductions (number of fatal and non-fatal cancers avoided) and the residual health risk (number of remaining cancer cases) at various radon in water levels.

TABLE XIII.6.—RESIDUAL CANCER RISK AND RISK REDUCTION FROM REDUCING RADON IN DRINKING WATER

Radon Level (pCi/L in water)	Residual fatal cancer risk (cases per year)	Residual non-fatal cancer risk (cases per year)	Risk reduction (fatal cancers avoided per year)[1]	Risk reduction (non-fatal cancers avoided per year)[1]
(Baseline)	168	9.7	0	0
4,0002 [2]	165	9.5	2.9	0.2
2,000	160	9.4	7.3	0.4
1,000	150	8.8	17.8	1.1
700	141	8.3	26.1	1.5
500	130	7.6	37.6	2.2
300	106	6.1	62.0	3.6
100	46.8	2.8	120	7.0

Notes:
[1] Risk reductions and residual risk estimates are slightly inconsistent due to rounding.
[2] 4000 pCi/L is equivalent to the AMCL estimated by the NAS based on SDWA provisions of Section 1412(b)(13).

Since preparing the prepublication edition of the NAS Report, the NAS has reviewed and slightly revised their unit risk estimates. EPA uses these updated unit risk estimates in calculating the baseline risks, health risk reductions, and residual risks. Under baseline assumptions (no control of radon exposure), approximately 168 fatal cancers and 9.7 non-fatal cancers per year are associated with radon exposures through CWSs. At a radon level of 4,000 pCi/L, approximately 2.9 fatal cancers and 0.2 non-fatal cancers per year are prevented. At 300 pCi/L, approximately 62.0 fatal cancers and 3.6 non-fatal cancers are prevented each year.

The Agency has developed monetized estimates of the health benefits associated with the risk reductions from radon exposures. The SDWA, as amended, requires that a cost-benefit analysis be conducted for each NPDWR, and places a high priority on better analysis to support rulemaking. The Agency is interested in refining its approach to both the cost and benefit analysis, and in particular recognizes that there are different approaches to monetizing health benefits. In the past, the Agency has presented benefits as cost per life saved, as in Table XIII.7.

The costs of reducing radon to various levels, assuming 100 percent compliance with an MCL, are summarized in Table XIII.7, which shows that, as expected, aggregate radon mitigation costs increase with decreasing radon levels. For CWSs, the costs per system do not vary substantially across the different radon levels evaluated. This is because the menu of mitigation technologies for systems with various influent radon levels remains relatively constant and are not sensitive to percent removal.

TABLE XIII.7.—ESTIMATED ANNUALIZED NATIONAL COSTS OF REDUCING RADON EXPOSURES

[$Million, 1997]

Radon level (pCi/L)	Central tendency estimate of annualized costs [2]	Total annualized national costs [3]	Total cost per fatal cancer case avoided
4000 [1]	34.5	43.1	14.9
2000	61.1	69.7	9.5

TABLE XIII.7.—ESTIMATED ANNUALIZED NATIONAL COSTS OF REDUCING RADON EXPOSURES—Continued
[$Million, 1997]

Radon level (pCi/L)	Central tendency estimate of annualized costs [2]	Total annualized national costs [3]	Total cost per fatal cancer case avoided
1000	121.9	130.5	7.3
700	176.8	185.4	7.1
500	248.8	257.4	6.8
300	399.1	407.6	6.6
100	807.6	816.2	6.8

[1] 4000 pCi/L is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).
[2] Costs include treatment, monitoring, and O&M costs only.
[3] Costs include treatment, monitoring, O&M, recordkeeping, reporting, and state costs for administration of water programs.

An alternative approach presented here for consideration as one measure of potential benefits is the monetary value of a statistical life (VSL) applied to each fatal cancer avoided. Since this approach is relatively new to the development of NPDWRs, EPA is interested in comments on these alternative approaches to valuing benefits, and will have to weigh the value of these approaches for future use.

Estimating the VSL involves inferring individuals' implicit tradeoffs between small changes in mortality risk and monetary compensation. In the HRRCA, a central tendency estimate of $5.8 million (1997$) is used in the monetary benefits calculations. This figure is determined from the VSL estimates in 26 studies reviewed in EPA's recent draft guidance on benefits assessment (USEPA 1998e), which is currently under review by the Agency's Science Advisory Board (SAB) and the Office of Management and Budget (OMB).

It is important to recognize the limitations of existing VSL estimates and to consider whether factors such as differences in the demographic characteristics of the populations and differences in the nature of the risks being valued have a significant impact on the value of mortality risk reduction benefits. Also, medical care or lost-time costs are not separately included in the benefits estimate for fatal cancers, since it is assumed that these costs are captured in the VSL for fatal cancers.

For non-fatal cancers, willingness to pay (WTP) data to avoid chronic bronchitis is used as a surrogate to estimate the WTP to avoid non-fatal lung and stomach cancers. The use of such WTP estimates is supported in the SDWA, as amended, at Section 1412(b)(3)(C)(iii): ''The Administrator may identify valid approaches for the measurement and valuation of benefits under this subparagraph, including approaches to identify consumer willingness to pay for reductions in health risks from drinking water contaminants.''

A WTP central tendency estimate of $536,000 is used to monetize the benefits of avoiding non-fatal cancers (Viscusi et al. 1991). The combined fatal and non-fatal health benefits are summarized in Table XIII.8. The annual health benefits range from $17.0 million for a radon level of 4000 pCi/L to $702 million at 100 pCi/L.

TABLE XIII.8.—ESTIMATED MONETIZED HEALTH BENEFITS FROM REDUCING RADON IN DRINKING WATER

Radon level (pCi/L)	Monetized health benefits, central tendency (annualized, $millions, 1997) [1]
4,000 [2]	17.0
2,000	42.7
1,000	103
700	152
500	219
300	362
100	702

Notes:
[1] Includes contributions from fatal and non-fatal cancers, estimated using central tendency estimates of the VSL of $5.8 million (1997$), and a WTP to avoid non-fatal cancers of $536,000 (1997$).
[2] 4000 pCi/L is equivalent to the AMCL estimated by the NAS based on SDWA provisions of Section 1412(b)(13).

Reductions in radon exposures might also be associated with non-quantifiable benefits. EPA has identified several potential non-quantifiable benefits associated with regulating radon in drinking water. These benefits may include any customer peace of mind from knowing drinking water has been treated for radon. In addition, if chlorination is added to the process of treating radon via aeration, arsenic pre-oxidation will be facilitated. Neither chlorination nor aeration will remove arsenic, but chlorination will facilitate conversion of Arsenic (III) to Arsenic (V). Arsenic (V) is a less soluble form that can be better removed by arsenic removal technologies. In terms of reducing radon exposures in indoor air, it has also been suggested that provision of information to households on the risks of radon in indoor air and available options to reduce exposure may be a non-quantifiable benefit that can be attributed to some components of a MMM program. Providing such information might allow households to make more informed choices than they would have in the absence of an MMM program about the need for risk reduction given their specific circumstances and concerns. In the case of the proposed radon rule, it is not likely that accounting for these non-quantifiable benefits would significantly alter the overall assessment.

The benefits calculated for this proposal are assumed to begin to accrue on the effective date of the rule and are based on a calculation referred to as the ''value of a statistical life'' (VSL), currently estimated at $5.8 million. The VSL is an average estimate derived from a set of 26 studies estimating what people are willing to pay to avoid the risk of premature mortality. Most of these studies examine willingness to pay in the context of voluntary acceptance of higher risks of immediate accidental death in the workplace in exchange for higher wages. This value is sensitive to differences in population characteristics and perception of risks being valued.

For the present rulemaking analysis, which evaluates reduction in premature mortality due to carcinogen exposure, some commenters have argued that the Agency should consider an assumed time lag or latency period in these calculations. Latency refers to the difference between the time of initial exposure to environmental carcinogens and the onset of any resulting cancer. Use of such an approach might reduce significantly the present value estimate.

The BEIR VI model and U.S. vital statistics, on which the estimate of lung cancers avoided is based, imply a probability distribution of latency periods between inhalation exposure to radon and increased probability of cancer death. EPA is interested in receiving comments on the extent to which the presentation of more detailed information on the timing of cancer risk reductions would be useful in evaluating the benefits of the proposed rule.

Latency is one of a number of adjustments or factors that are related to an evaluation of potential benefits associated with this rule, how those benefits are calculated, and when those economic benefits occur. Other factors which may influence the estimate of economic benefits associated with avoided cancer fatalities include (1) A possible ''cancer premium'' (i.e., the additional value or sum that people may be willing to pay to avoid the experiences of dread, pain and suffering, and diminished quality of life associated with cancer-related illness and ultimate fatality); (2) the willingness of people to pay more over time to avoid mortality risk as their income rises; (3) a possible premium for accepting involuntary risks as opposed to voluntary assumed risks; (4) the greater risk aversion of the general population compared to the workers in the wage-risk valuation studies; (5) ''altruism'' or the willingness of people to pay more to reduce risk in other sectors of the population; and (6) a consideration of health status and life years remaining at the time of premature mortality. Use of certain of these factors may significantly increase the present value estimate. EPA therefore believes that adjustments should be considered simultaneously. The Agency also believes that there is currently neither a clear consensus among economists about how to simultaneously analyze each of these adjustments nor is there adequate empirical data to support definitive quantitative estimates for all potentially significant adjustment factors. As a result, the primary estimates of economic benefits presented in the analysis of this rule rely on the unadjusted $5.8 million estimate. However, EPA solicits comment on whether and how to conduct these potential adjustments to economic benefits estimates together with any rationale or supporting data commenters wish to offer. Because of the complexity of these issues, EPA will ask the Science Advisory Board (SAB) to conduct a review of these benefits transfer issues associated with economic valuation of adjustments in mortality risks. In its analysis of the final rule, EPA will attempt to develop and present an analysis and estimate of the latency structure and associated benefits transfer issues outlined previously consistent with the recommendations of the SAB and subject to resolution of any technical limitations of the data and models.

E. Cost Analysis

1. Total National Costs of Compliance with MCL Options

Table XIII.9 summarizes the estimates of total national costs of compliance with the range of potential MCLs considered. The table is divided into two major groupings; the first grouping displays the estimated costs to systems and the second grouping displays the estimated costs to States. State costs, presented in Table XIII.9, were developed as part of the analyses to comply with the Unfunded Mandates Reform Act (UMRA) and also the Paperwork Reduction Act (PRA). Additional information on State costs is provided in Section 8 of the RIA and also in Section VIII of this preamble.

TABLE XIII.9.—SUMMARY OF ESTIMATED COSTS UNDER THE PROPOSED RADON RULE ASSUMING 100% COMPLIANCE WITH AN MCL OF 300 PCI/L

[$ Millions] [1]

	3 percent cost of capital	7 percent cost of capital	10 percent cost of capital
Costs to Water Systems			
Total Capital Costs (20 years, undiscounted)	2,463	2,463	2,463
Annual Costs			
Annualized Capital	165.6	232.5	289.4
Annual O&M	152.4	152.4	152.4
Total Annual Treatment	318.0	385.0	441.8
Monitoring Costs	14.1	14.1	14.1
Recordkeeping and Reporting Costs [2]	6.1	6.1	6.1
Total Annual Costs to Water Systems [3]	338.2	405.1	461.6
Costs to States			
Administration of Water Programs	2.5	2.5	2.5
Total Annual State Costs	2.5	2.5	2.5
Total Annual Costs of Compliance [4]	340.6	407.6	464.4

1. Assumes no MMM program implementation costs (*e.g.,* all systems comply with 300 pCi/L).
2. Figure represents average annual burden over 20 years.
3. Costs include treatment, monitoring, O&M, recordkeeping, and reporting costs to water systems.
4. Totals have been rounded. Costs include treatment, monitoring, O&M, recordkeeping, reporting, and state costs for administration of water programs.

2. Quantifiable and Non-quantifiable Costs

The capital and operating and maintenance (O&M) costs of mitigating radon in Community Water Systems (CWSs) were estimated for each of the radon levels evaluated. The costs of reducing radon in community ground water to specific target levels were calculated using the cost curves discussed in Section 7.5 and the matrix of treatment options presented in Section 7.6 of the RIA. For each radon level and system size stratum, the number of systems that need to reduce radon levels by up to 50 percent, 80 percent and 99 percent were calculated. Then, the cost curves for the distributions of technologies dictated by the treatment matrix were applied to the appropriate proportions of the systems. Capital and O&M costs were then calculated for each system, based on typical estimated design and average flow rates. These flow rates were calculated on spreadsheets using equations from EPA's Baseline Handbook (USEPA 1999e). The equations and parameter values relating system size to flow rates are presented in Appendix C of the RIA. The technologies addressed in the cost estimation included a number of aeration and granular activated carbon (GAC) technologies described in Section 7.2 of the RIA, as well as storage, regionalization, and disinfection as a post-treatment. To estimate costs, water systems were assumed, with a few exceptions to simulate site-specific problems, to select the technology that could reduce radon to the selected target level at the lowest cost. CWSs were also assumed to treat separately at every source from which water was obtained and delivered into the distribution system.

EPA has attempted to note potential non-quantifiable benefits when the Agency believes they might occur, as in the case of peace-of-mind benefits from radon reduction. The Agency recognizes that there may also be non-quantifiable disbenefits, such as anxiety on the part of those near aeration plants or those who find out that their radon levels are high. It is not possible to determine whether the net results of such psychological effects would be positive or negative. The inclusion of non-quantifiable benefits and costs in this analysis are not likely to alter the overall results of the benefit-cost analysis for the proposed radon rule.

F. Economic Impact Analysis

A summary analysis of the impacts on small entities is shown in Section XIV.B of this preamble (Regulatory Flexibility Act). An analysis of the impacts on State, local, and tribal governments is shown in Section XIV.C (Unfunded Mandates Reform Act). For information on how this proposed rulemaking may impact Indian tribal governments, see Section XIV.I of today's preamble. Information on the types of information that States will be required to collect, as well as EPA's estimate of the burden and reporting requirements for this proposed rulemaking, is shown in Section XIV.D (Paperwork Reduction Act). EPA's assessment of the impacts that this proposed rulemaking may have on low-income and minority populations, as well as any potential concerns regarding children's health, are shown in Section XIV.F (Environmental Justice) and Section XIV.G (Protection of Children from Environmental Health Risks and Safety Risks) of today's preamble.

G. Weighing the Benefits and Costs

1. Incremental Costs and Benefits of Radon Removal

TABLE XIII.10.—ESTIMATES OF THE ANNUAL INCREMENTAL RISK REDUCTION, COSTS, AND BENEFITS OF REDUCING RADON IN DRINKING WATER ASSUMING 100% COMPLIANCE WITH AN MCL

[$ Millions 1997]

	Radon Level, pCi/L						
	4000 [1]	2000	1000	700	500	300	100
Incremental Risk Reduction, Fatal Cancers Avoided Per Year	2.9	4.4	10.5	8.4	11.5	24.4	58.4
Incremental Risk Reduction, Non-Fatal Cancers Avoided Per Year	0.2	0.3	0.6	0.4	0.8	1.3	3.5
Annual Incremental Monetized Benefits, $ Million Per Year	17.0	25.7	61.0	48.7	67.1	142	341
Annual Incremental Radon Mitigation Costs, $ Million Per Year [2]	34.5	26.6	60.8	54.9	72.0	150.3	408.5

[1] 4000 pCi/L is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).
[2] Costs include treatment, monitoring, and O&M costs only.

2. Impacts on Households

The cost impact of reducing radon in drinking water at the household level was also assessed. As expected, costs per household increase as system size decreases as shown in Table XIII.11.

TABLE XIII.11.—ANNUAL COSTS PER HOUSEHOLD FOR COMMUNITY WATER SYSTEMS TO TREAT TO VARIOUS RADON LEVELS [1]

[$, 1997]

Radon level (pCi/L)	VVS (25–100)	VVS (101–500)	VS (501–3300)	S (3301–10K)	M (10,001–100K)	L (> 100K)
Households Served by PUBLIC Systems Above Radon Level by Population Served						
4000 [2]	256.5	91.0	22.7	14.3	6.2	4.5
2000	259.0	92.8	23.5	14.9	7.1	5.2
1000	262.5	94.8	24.6	15.4	8.6	6.4
700	264.4	96.0	25.2	15.9	9.6	7.2
500	266.3	97.1	25.9	16.4	10.6	8.1

TABLE XIII.11.—ANNUAL COSTS PER HOUSEHOLD FOR COMMUNITY WATER SYSTEMS TO TREAT TO VARIOUS RADON LEVELS [1]—Continued

[$, 1997]

Radon level (pCi/L)	VVS (25–100)	VVS (101–500)	VS (501–3300)	S (3301–10K)	M (10,001–100K)	L (> 100K)
300	269.5	99.3	26.9	17.4	12.4	9.5
100	278.8	107.1	29.1	20.1	16.2	12.8
Households Served by PRIVATE Systems Above Radon Level by Population Served						
4000 [2]	372.4	141.1	30.3	22.8	6.6	4.4
2000	375.8	143.7	31.2	23.7	7.5	5.1
1000	380.5	146.3	32.6	24.7	9.1	6.3
700	383.1	147.8	33.4	25.4	10.1	7.1
500	385.6	149.4	34.2	26.2	11.2	7.9
300	389.8	152.2	35.5	27.7	13.1	9.4
100	401.5	162.4	37.9	32.1	17.1	12.6

[1] Reflects total household costs for systems to treat down to these levels. Because EPA expects that most systems will comply with the AMCL/MCL, most systems will not incur these household costs.
[2] 4000 pCi/L is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

Costs to households are higher for households served by smaller systems than larger systems for two reasons. First, smaller systems serve far fewer households than larger systems and, consequently, each household must bear a greater percentage share of the capital and O&M costs. Second, smaller systems tend to have higher influent radon concentrations that, on a per-capita or per-household basis, require more expensive treatment methods (e.g., one that has an 85 percent removal efficiency rather than 50 percent) to achieve the applicable radon level.

To further evaluate the impacts of these household costs, the costs per household were compared to median household income data for each system-size category. The results of this calculation, presented in Table XIII.12 for public and private systems, indicate a household's likely share of average incremental costs in terms of the median income. Actual costs for individual households will reflect higher or lower income shares depending on whether they are above or below the median household income (approximately $30,000 per year) and whether the water system incurs above average or below average costs for installing treatment. For all system sizes but very very small private systems, average household costs as a percentage of median household income are less than one percent for households served by either public or private systems. Average impacts exceed one percent only for households served by very very small private systems, which are expected to face average impacts of 1.12 percent at the 4,000 pCi/l level and 1.35 percent at the 300 pCi/l level and for households served by very very small public systems at the 300 pCi/l level, whose average costs barely exceed one percent. Similar to the average cost per household results on which they are based, average household impacts exhibit little variability across radon levels.

TABLE XIII.12.—PER HOUSEHOLD IMPACT BY COMMUNITY GROUNDWATER SYSTEMS AS A PERCENTAGE OF MEDIAN HOUSEHOLD INCOME

[Percent]

Radon level, pCi/L	Average Impact to Households Served by Public Systems Exceeding Radon Levels						Average Impact to Households Served by Private Systems Exceeding Radon Levels					
	VVS (25–100)	VVS (101–500)	VS	S	M	L	VVS (25–100)	VVS (101–500)	VS	S	M	L
4000 [1]	0.86	0.30	0.13	0.06	0.03	0.02	1.12	0.35	0.16	0.07	0.04	0.02
2000	0.92	0.36	0.12	0.05	0.02	0.01	1.19	0.42	0.16	0.09	0.02	0.01
1000	0.96	0.38	0.13	0.05	0.02	0.01	1.24	0.44	0.16	0.09	0.03	0.01
700	0.98	0.38	0.13	0.06	0.03	0.02	1.27	0.45	0.17	0.09	0.03	0.01
500	1.00	0.39	0.13	0.06	0.03	0.02	1.30	0.45	0.17	0.09	0.03	0.01
300	1.05	0.40	0.14	0.06	0.03	0.02	1.35	0.47	0.18	0.10	0.04	0.02
100	1.17	0.44	0.15	0.07	0.05	0.03	1.51	0.51	0.19	0.12	0.05	0.02

[1] 4000 pCi/L is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

3. Summary of Annual Costs and Benefits

Table XIII.13 reveals that at a radon level of 4000 pCi/L (equivalent to the AMCL estimated in the NAS Report), annual costs of 100 percent compliance with an MCL are approximately twice the annual monetized benefits. For radon levels of 1000 pCi/L to 300 pCi/L, the central tendency estimates of annual costs are above the central tendency estimates of the monetized benefits.

TABLE XIII.13.—ESTIMATED NATIONAL ANNUAL COSTS AND BENEFITS [1] OF REDUCING RADON EXPOSURES ASSUMING 100% COMPLIANCE WITH AN MCL—CENTRAL TENDENCY ESTIMATE

[$ Millions, 1997]

Radon level (pCi/L)	Annualized treatment costs [2]	Total annualized costs [3]	Cost per fatal cancer avoided	Annual monetized benefits
4000 [4]	34.5	43.1	14.9	17.0
2000	61.1	69.7	9.5	42.7
1000	121.9	130.5	7.3	103
700	176.8	185.4	7.1	152
500	248.8	257.4	6.8	219
300	399.1	407.6	6.6	362
100	807.6	816.2	6.8	702

Notes:

[1] Benefits are calculated for stomach and lung cancer assuming that risk reduction begins immediately. Estimates assume a $5.8 million value of a statistical life and willingness to pay of $536,000 for non-fatal cancers.

[2] Costs are annualized over twenty years using a discount rate of seven percent. Costs include treatment, monitoring, and O&M costs.

[3] Costs include treatment, monitoring, O&M, recordkeeping, reporting, and state costs for administration of water programs.

[4] 4000 pCi/L is equivalent to the AMCL estimated by the NAS based on SDWA requirements of Section 1412(b)(13).

Because the costs of compliance with an MCL for small systems outweigh the benefits at each radon level (Table XIII.14), the MMM option was recommended for small systems to alleviate some of the financial burden to these systems and the households they serve and to realize equivalent or greater benefits at much lower costs. The results of the benefit-cost analyses for MMM implementation scenarios are shown at the end of this section and also in Section 9 of the RIA.

TABLE XIII.14.— ESTIMATED ANNUAL COSTS AND BENEFITS FOR 100% COMPLIANCE WITH AN MCL BY SYSTEM SIZE

[$Millions, 1997]

Radon level (pCi/l)	Parameter [1]	System size					
		25–100	101–500	501–3300	3301–10,000	10,001–100K	>100K
4000	Benefits	0.16	0.79	2.7	2.8	7.0	3.6
	Costs	7.8	14.3	6.3	2.9	2.7	0.5
2000	Benefits	0.41	2.0	6.8	6.9	17.7	9.0
	Costs	13.2	22.7	11.6	5.7	6.3	1.6
1000	Benefits	1.0	4.8	16.3	16.7	42.6	21.6
	Costs	23.1	36.5	24.7	13.4	18.9	5.3
700	Benefits	1.5	7.1	24.1	24.6	62.9	31.9
	Costs	30.6	46.5	36.3	21.1	32.8	9.5
500	Benefits	2.1	10.2	34.7	35.4	90.6	45.9
	Costs	39.4	57.9	50.8	32.0	53.0	15.6
300	Benefits	3.5	16.9	57.3	58.6	150	75.9
	Costs	55.6	79.3	78.8	56.1	99.3	26.9
100	Benefits	7.2	32.7	111	113	290	147
	Costs	93.4	134	147	122	238	73.5

[1] Costs do not include recordkeeping, reporting, or state costs for administration of water programs. Recordkeeping and reporting costs are estimated at $6.1 million for all system sizes and State administration costs for water programs are estimated at $2.5 million.

Total costs to public and private water systems, by size, were also evaluated in the RIA. Table XIII.15 presents the total annualized costs for public and private systems by system size category for all radon levels evaluated in the RIA. The costs are comparable for public and private systems across system sizes for all options. This pattern may be due in large part to the limited number of treatment options assumed to be available to either public or private systems in mitigating radon.

TABLE XIII.15.—AVERAGE ANNUAL COST PER SYSTEM

[$Thousands, 1997]

Radon Level (pCi/l)	Average costs to public systems exceeding radon levels						Average costs to private systems exceeding radon levels					
	VVS (25–100)	VVS (101–500)	VS	S	M	L	VVS (25–100)	VVS (101–500)	VS	S	M	L
4000	8.2	12.4	18.5	49.3	82.3	484.9	7.6	10.1	15.6	43.7	72.1	468.5
2000	8.3	12.6	19.1	51.3	94.1	560.7	7.7	10.3	16.2	45.5	82.4	541.8
1000	8.4	12.9	26.6	60.1	115.9	693.4	7.8	10.5	16.8	47.3	100.2	670.2
700	8.5	13.0	27.2	61.9	129.0	758.3	7.9	10.6	17.1	48.7	111.7	752.7
500	8.5	13.2	27.8	63.7	143.2	847.8	7.9	10.7	17.5	50.3	123.9	841.6
300	8.6	13.5	28.8	67.4	167.1	1000.4	8.0	10.9	18.1	53.3	144.7	992.9
100	8.9	14.6	31.0	77.2	219.1	1345.3	8.2	11.6	19.1	61.8	189.6	1333.1

TABLE XIII.15.—AVERAGE ANNUAL COST PER SYSTEM—Continued

[$Thousands, 1997]

Radon Level (pCi/l)	Average costs to public systems exceeding radon levels						Average costs to private systems exceeding radon levels					
	VVS (25–100)	VVS (101–500)	VS	S	M	L	VVS (25–100)	VVS (101–500)	VS	S	M	L
Annual Per System Cost for those Systems Below Radon Levels: Monitoring Costs Only												
All	0.3	0.3	0.4	0.6	1.1	2.6	0.3	0.3	0.4	0.6	1.1	2.6

4. Benefits From the Reduction of Co-Occurring Contaminants

The occurrence patterns of industrial pollutants are difficult to clearly define at the national level relative to a naturally occurring contaminant such as radon. Similarly, the Agency's re-evaluation of radon occurrence has revealed that the geographic patterns of radon occurrence are not significantly correlated with other naturally occurring inorganic contaminants that may pose health risks. Thus, it is not likely that a clear relationship exists between the need to install radon treatment technologies and treatments to remove other contaminants. On the other hand, technologies used to reduce radon levels in drinking water have the potential to reduce concentrations of other pollutants as well. Aeration technologies will also remove volatile organic contaminants from contaminated ground water. Similarly, granular activated carbon (GAC) treatment for radon removal effectively reduces the concentrations of organic (both volatile and nonvolatile) chemicals and some inorganic contaminants. Aeration also tends to oxidize dissolved arsenic (a known carcinogen) to a less soluble form that is more easily removed from water. The frequency and extent that radon treatment would also reduce risks from other contaminants has not been quantitatively evaluated.

5. Impacts on Sensitive Subpopulations

The SDWA, as amended, includes specific provisions in Section 1412(b)(3)(C)(i)(V) to assess the effects of the contaminant on the general population and on groups within the general population such as children, pregnant women, the elderly, individuals with a history of serious illness, or other subpopulations that are identified as likely to be at greater risk of adverse health effects due to exposure to contaminants in drinking water than the general population. The NAS Report concluded that there is insufficient scientific information to permit separate cancer risk estimates for potential subpopulations such as pregnant women, the elderly, children, and seriously ill persons. The NAS Report did note, however, that according to the NAS model for the cancer risk from ingested radon, which accounts for 11 percent of the total fatal cancer risk from radon in drinking water, approximately 30 percent of the fatal lifetime cancer risk is attributed to exposure between ages 0 to 10.

The NAS Report identified smokers as the only group that is more susceptible to inhalation exposure to radon progeny (NAS 1999b). Inhalation of cigarette smoke and radon progeny result in a greater increased risk than if the two exposures act independently to induce lung cancer. NAS estimates that ‘‘ever smokers’’ (more than 100 cigarettes over a lifetime) may be more than five times as sensitive to radon progeny as ‘‘never smokers’’ (less than 100 cigarettes over a lifetime). Using current smoking prevalence data, EPA's preliminary estimate for the purposes of the HRRCA is that approximately 85 percent of the cases of radon-induced cancer will occur among current and former smokers. This population of current and former smokers, which consists of 58 percent of the male and 42 percent of the female population, will also experience the bulk of the risk reduction from radon exposure reduction in drinking water supplies.

6. Risk Increases From Other Contaminants Associated With Radon Exposure Reduction

As discussed in Section 7.2 of the RIA, the need to install radon treatment technologies may require some systems that currently do not disinfect to do so. Case studies (US EPA 1998j) of twenty-nine small to medium water systems that installed treatment (24 aeration, 5 GAC) to remove radon from drinking water revealed only two systems that reported adding disinfection (both aeration) with radon treatment (the other systems either had disinfection already in place or did not add it). In practice, the tendency to add other disinfection with radon treatment may be much more significant than these case studies indicate. EPA also realizes that the addition of chlorination for disinfection may result in risk-risk tradeoffs, since, for example, the disinfection technology reduces potential for infectious disease risk, but at the same time can result in increased exposures to disinfection by-products (DBPs). This risk-risk trade-off is addressed by the recently promulgated Disinfectants and Disinfection By-Products NPDWR (63 FR 69390). This rule identified MCLs for the major DBPs, with which all CWSs and NTNCWSs must comply. These MCLs set a risk ceiling from DBPs that water systems adding disinfection in conjunction with treatment for radon removal could face. The formation of DBPs correlates with the concentration of organic precursor contaminants, which tend to be much lower in ground water than in surface water. In support of this statement, the American Water Works Association's WATERSTATS survey (AWWA 1997) reports that more than 50% of the ground water systems surveyed have average total organic carbon (TOC) raw water levels less than 1 mg/L and more than 80% had TOC levels less than 3 mg/L. On the other hand, WATERSTATS reports that less than 6% of surface water systems surveyed had raw water TOC levels less than 1 mg/L and more than 50% had raw water TOC levels greater than 3 mg/L. In fact, this survey reports that more than 85% of surface water systems had finished water TOC levels greater than 1 mg/L.

The NAS Report addressed several important potential risk-risk tradeoffs associated with reducing radon levels in drinking water, including the trade-off between risk reduction from radon treatment that includes post-disinfection with the increased potential for DBP formation (NAS 1999b). The report concluded that, based upon median and average total trihalomethane (THM) levels taken from a 1981 survey, ground water systems would face an incremental individual lifetime cancer risk due to chlorination byproducts of 5×10^{-5}. It should be emphasized that this risk is based on average and median Trihalomethane (THM) occurrence information that does not segregate systems that disinfect from those that do. It should also be noted that this survey pre-dates the promulgation of the Stage I Disinfection Byproducts Rule by almost twenty years. Further, the NAS Report points out that this average DBP risk is smaller than the average individual lifetime fatal cancer risk associated with baseline radon exposures from ground water (untreated for radon), which is estimated at 1.2×10^{-4} using a mean radon concentration of 213 pCi/L.

While this risk comparison is instructive, a more meaningful relationship for the proposed radon rule would be to compare the trade-off between radon risk reduction from radon treatment and introduced DBP risk from disinfection added along with radon treatment. EPA emphasizes that this risk trade-off is only of concern to the small minority (<1%) of small ground water systems with radon levels above the AMCL of 4000 pCi/L and to the small minority of large ground water systems that are not already disinfecting. Presently, approximately half of all small community ground water systems already have disinfection in place, as shown in Table XIII.5. The proportion of systems having disinfection in place increases as the system's size increases; >95% of large ground water systems currently disinfect. In terms of the populations served, 83% of persons served by small community ground water systems (those serving 10,000 persons or fewer) already receive disinfected drinking water and 95% of persons served by large ground water systems already receive disinfected drinking water. As shown in Tables XIII.16 and XIII.17, even for those ground water systems adding both radon treatment and disinfection, this risk-risk trade-off tends to be very favorable, since the risk reduction from radon removal greatly outweighs the added risk from DBP formation.

An estimate of the risk reduction due to treatment of radon in water for various removal percentages and finished water concentrations is provided in Table XIII.16. These risk reductions are much greater than NAS's estimate of the average lifetime risk from DBP exposure for ground water systems, by factors ranging from 3.5 for low radon removal efficiencies (50%) to more than 130 for higher radon removal efficiencies (>95%).

TABLE XIII.16.—RADON RISK REDUCTIONS RESULTING FROM WATER TREATMENT

Radon Influent (Raw Water) level, pCi/L	Required removel efficiency (percent)	Reduced lifetime risk resulting from Water Treatment for Radon in Drinking Water [1]
500	52	1.7×10^{-4}
750	68	3.4×10^{-4}
1000	76	5.1×10^{-4}
2500	90	1.5×10^{-3}
4000	94	2.5×10^{-3}
10000	98	6.5×10^{-3}

[1] Assumes that water is treated to 80% of the radon MCL.

Table XIII.17 demonstrates the risk-risk trade-off between the risk reduction from radon removal and the risks introduced from total trihalomethanes (TTHM) for two scenarios: (1) the resulting TTHM level is 0.008 mg/L (10% of the TTHM MCL) and (2) the resulting TTHM level is 0.080 mg/L (the TTHM MCL). The table demonstrates that the risk-risk trade-off is favorable for treatment with disinfection, even for situations where radon removal efficiencies are low (50%) and TTHM levels are present at the MCL. While accounting quantitatively for the increased risk from DBP exposure for systems adding chlorination in conjunction with treatment for radon may somewhat decrease the monetized benefits estimates, disinfection may also produce additional benefits from the reduced risks of microbial contamination.

TABLE XIII.17.—RADON RISK REDUCTION FROM TREATMENT COMPARED TO DBP RISKS

Radon influent (Raw Water) level pCi/L	Estimated risk ratios: (lifetime risk reduction from radon removal [1] / lifetime average risk from TTHMs in chlorinated groundwater)		
	(NAS) [2]	TTHMs present at 10% of TTHM MCL (0.080 mg/L) [3]	TTHMs present at MCL
500	4	30	3
750	7	60	6
1000	10	90	9
2500	30	300	30
4000	50	500	50
10000	130	1200	120

Notes: [1] From Table XIII.16.

[2] From Appendix D in: National Research Council, *Risk Assessment of Radon in Drinking Water,* National Academy Press, Washington, DC. 1999. DBP concentrations are from a 1981 study and therefore pre-date the Stage 1 DBP NPDWR.

[3] US EPA Regulatory Impact Analysis for the Stage 1 Disinfectants/Disinfection Byproducts Rule. Prepared by The Cadmus Group. November 12, 1998. Analysis is based on the 95% upper confidence interval value from the Integrated Risk Information System (IRIS) lifetime unit risks for each THM. TTHM is assumed to comprised by 70% chloroform, 21% bromodichloromethane, 8% dibromochloromethane, and 1% bromoform.

[4] US EPA. Regulatory Impact Analysis for the Stage 1 Disinfectants/Disinfection Byproducts Rule. Based on the 95% upper confidence interval value from the Integrated Risk Information System (IRIS) for the lifetime unit risk for dibromochloromethane (2.4×10^{-6} risk of cancer case over 70 years of exposure).

7. Other Factors: Uncertainty in Risk, Benefit, and Cost Estimates

Estimates of health benefits from radon reduction are uncertain. EPA is including an uncertainty analysis of radon in drinking water risks in Section XII of the preamble to the proposed radon rule. A brief discussion on the uncertainty analysis is also shown in Section 10 of the RIA (USEPA 1999f) for radon in drinking water. Monetary benefit estimates are also affected by the VSL estimate that is used for fatal cancers. The WTP valuation for non-fatal cancers has less impact on benefit estimates because it contributes less than 1 percent to the total benefits estimates, due to the fact that there are few non-fatal cancers relative to fatal cancers and they receive a much lower monetary valuation.

8. Costs and Benefits of Multimedia Mitigation Program Implementation Scenarios

In addition to evaluating the costs and benefits across a range of radon levels, EPA has evaluated five scenarios that reduce radon exposure through the use of MMM programs. The implementation assumptions for each scenario are described in the next section. These five scenarios are described in detail in Section 9 of the RIA. For the MMM implementation analysis, systems were assumed to mitigate water to the 4,000 pCi/L Alternative Maximum Contaminant Level (AMCL), if necessary, and that equivalent risk reduction between the AMCL and the radon level under evaluation would be achieved through a MMM program. Therefore, the actual number of cancer cases avoided is the same for the MMM implementation scenarios as for the water mitigation only scenario. A complete discussion on why MMM is expected to achieve equal or greater risk reduction is shown in Section VI.B of the preamble for the proposed radon rule.

For the RIA, EPA used a simplified approach to estimating costs of mitigating indoor air radon risks. A point estimate of the average cost per life saved under the current voluntary radon mitigation programs served as the basis for estimating the costs of risk reduction under the MMM options. The Agency has estimated the average screening and mitigation cost per fatal lung cancer avoided to be approximately $700,000, assuming the current distribution of radon in indoor air, that all homes would be tested for radon in indoor air, and that all homes at or above EPA's voluntary action level of 4 pCi/L would be mitigated. This value was originally derived based on data gathered in 1991. The same value has been used in the RIA, without adjustment for inflation, after discussions with personnel from EPA's Office of Radiation and Indoor Air indicated that screening and mitigation costs have not increased since 1991.

9. Implementation Scenarios

EPA evaluated the annual cost of five MMM implementation scenarios that span the range of participation in MMM programs that might occur when a radon NPDWR is implemented. Each scenario assumes a different proportion of States will comply with the AMCL and implement MMM programs. It has been assumed that ''50 percent of States'' implies 50 percent of systems in the U.S; ''60 percent of States'' implies 60 percent of systems, and so on.

Scenario A: 50 percent of States implement MMM programs.
Scenario B: 60 percent of States implement MMM programs.
Scenario C: 70 percent of States implement MMM programs.
Scenario D: 80 percent of States implement MMM programs.
Scenario E: 95 percent of States implement MMM programs.

States that do *not* implement MMM programs instead must review and approve any system-level MMM programs prepared by community water systems. In these States, regardless of scenario, 90 percent of systems are assumed to comply with the AMCL *and* to implement a system-level MMM program and 10 percent are assumed to comply with the MCL. EPA requests comment on whether this is an appropriate assumption.

10. Costs and Benefits of MMM Implementation Scenarios

Table XIII.18 shows the total annual system-level and State-level costs for each MMM scenario, assuming an MCL of 300 pCi/L and AMCL of 4,000 pCi/L. Additional MMM scenario cost and benefit tables for MCL levels of 100, 500, 700, 1000, 2000, and 4000 pCi/L are shown in Appendix E of the RIA. System, State, and MMM mitigation costs decrease from $121.1 million to $60.4 million as the percentage of States implementing MMM programs increases from 50 to 95 percent. System-level costs decrease from $104 million to $47 million as the percentage of States implementing MMM programs increases from 50 to 95 percent. Costs for actual mitigation of radon in indoor air rise from $3.9 million to $4.1 million as the percentage of States implementing MMM programs rises from 50 to 95 percent. Note that these mitigation costs are relatively flat because all scenarios assume that 95 percent or more of the risk reduction will be achieved through MMM at either the State or local level.

Table XIII.19 represents the ratios of benefits to costs of MMM programs for each scenario, by system size. Only the ratios in the bottom row of the table include costs to the States. The balance of the numbers presented here represent local benefits and costs only and as such, somewhat overstate the net benefits of the scenarios. Benefit-cost ratios are generally less than one for the smallest system size category (systems serving less than 500 people), but greater than one for larger systems under all five scenarios. For larger systems, benefit-cost ratios range from 2.6 for systems serving 501–3,300 people under Scenario A to approximately 41.4 for systems serving 10,001 to 100,000 people under Scenario E. Overall benefit-cost ratios are over one for all five scenarios. This pattern is seen primarily because a larger proportion of smaller systems have influent radon levels exceeding 4000 pCi/L. A larger proportion of small systems versus large systems therefore, incur water mitigation costs to comply with the AMCL.

Table XIII.20 shows the net benefits (benefits minus costs) of the various MMM implementation scenarios. As would be expected from the benefit-cost ratios shown in Table XIII.19, all systems serving more than 500 people realize net positive benefits under all five scenarios. By far the largest proportion of net benefits is realized by systems serving 10,001 to 100,000 people.

TABLE XIII.18 (A).—ANNUAL SYSTEM—LEVEL AND STATE—LEVEL COSTS ASSOCIATED WITH THE MULTIMEDIA MITIGATION AND AMCL OPTION

[$ Millions/Year] [MCL=300 pCi/L]

System size	Scenario A 45% implement system-level MMM program; 5% mitigate water to 300 piC/L MCL; 95% mitigate water to 4000 piC/L AMCL	Scenario B 36% implement system-level MMM program; 4% mitigate water to 300 piC/L MCL; 96% mitigate water to 4000 piC/L AMCL	Scenario C 27% implement system-level MMM program; 3% mitigate water to 300 piC/L MCL; 97% mitigate water to 4000 piC/L AMCL	Scenario D 18% implement system-level MMM program; 2% mitigate water to 300 piC/L MCL; 98% mitigate water to 4000 piC/L AMCL	Scenario E 5% implement system-level MMM program; 5% mitigate water to 300 piC/L MCL; 99.5% mitigate water to 4000 piC/L AMCL
System Costs for Water Mitigation ($ millions/year)					
25–100	10.2	9.7	9.3	8.8	8.1
101–500	17.6	16.9	16.3	15.6	14.6
501–3300	9.9	9.2	8.5	7.7	6.7
3301–10,000	5.5	5.0	4.5	3.9	3.1
10,001–100,000	7.5	6.6	5.6	4.6	3.2
>100,000	2.0	1.7	1.4	1.1	0.7
Total CWS Water Mitigation Costs	52.7	49.1	45.4	41.8	36.3
Water System Administration Costs ($ millions/year)					
25–100	17.0	14.0	11.0	8.0	3.7
101–500	17.4	14.3	11.3	8.2	3.8
501–3300	12.0	9.9	7.8	5.7	2.6
3301–10,000	3.0	2.5	1.9	1.4	0.6
10,001–100,000	1.7	1.4	1.1	0.8	0.4
>100,000	0.1	0.1	0.1	0.0	0.0
Total CWS Administrative Costs	51.2	42.1	33.1	24.1	11.1
Total CWS Water Mitigation and Administrative Costs	104.0	91.2	78.5	65.9	47.4

TABLE XIII.18 (B).—STATE MMM ADMINISTRATIVE COSTS

[$ millions/year]

	Scenario A 50% of states implement state-wide MMM programs; 45% of CWS implement system-level MMM program	Scenario B 60% of states implement state-wide MMM program; 35% of CWS implement system-level MMM program	Scenario C 70% of states implement state-wide MMM program; 25% of CWS implement system-level MMM program	Scenario D 80% of states implement state-wide MMM program; 15% of CWS implement system-level MMM program	Scenario E 95% of states implement state-wide MMM program; 5% of CWS implement system-level MMM program
State costs associated with State-wide MMM program administration, reviewing system-level MMM programs, and reviewing system-level water mitigation requirements are not distributable across different system sizes.					
State Administration Costs for Water Mitigation	2.5	2.5	2.5	2.5	2.5
State Administration Costs for State-Level MMM Mitigation	2.9	3.5	4.1	4.7	5.6
State Administration Costs for System-Level MMM Mitigation	7.8	6.1	4.4	2.6	0.9
Total State Administration Costs	13.2	12.1	10.9	9.8	8.9

TABLE XIII.18 (C).—MMM TESTING AND MITIGATION COSTS

[$ million/year]

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
CWS MMM Costs	1.9	1.5	1.1	0.7	0.2
State MMM Costs	2.1	2.5	2.9	3.3	3.9
Total MMM Costs	3.91	3.95	3.99	4.03	4.12

TABLE XIII.18 (C).—MMM TESTING AND MITIGATION COSTS—Continued

[$ million/year]

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Total Costs (From Tables XIII.18 A, B, and C)	121.1	107.3	93.4	79.7	60.4

TABLE XIII.19.—RATIO OF BENEFITS AND COSTS BY SYSTEM SIZE FOR EACH SCENARIO (MCL=300 PCI/L)

System size	Benefits, $M	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
25–100	3.5	0.13	0.14	0.17	0.21	0.30
101–500	16.9	0.48	0.53	0.61	0.70	0.92
501–3,300	58.0	2.59	2.98	3.51	4.27	6.23
3,301–10,000	59.2	6.87	7.85	9.16	11.0	15.61
10,001–100,000	147.3	15.82	18.35	21.84	26.96	41.43
>100,000	76.7	37.16	43.70	53.04	67.44	113.68
OVERALL	361.6	2.98	3.37	3.87	4.54	5.99

TABLE XIII.20.—NET BENEFITS BY SYSTEM SIZE FOR EACH SCENARIO [1]

System size	Benefits, $M	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
25–100	3.5	(24.3)	(20.7)	(17.1)	(13.5)	(8.3)
101–500	16.9	(18.7)	(14.8)	(11.0)	(7.1)	(1.6)
501–3,300	58.0	35.6	38.6	41.5	44.4	48.7
3,301–10,000	59.2	50.6	51.7	52.7	53.8	55.4
10,001–100,000	147.3	138.0	139.3	140.6	141.8	143.7
>100,000	76.7	74.6	74.9	75.3	75.6	76.0
OVERALL	361.6	240.5	254.3	268.2	281.9	301.2

[1] Parentheses indicate negative numbers.

H. Response to Significant Public Comments on the February 1999 HRRCA

To provide the public with opportunities to comment on the Health Risk Reduction and Cost Analysis (HRRCA) for radon in drinking water, the Agency published the HRRCA in the **Federal Register** on February 26, 1999 (64 FR 9559). The HRRCA was published six months in advance of this proposal and illustrated preliminary cost and benefit estimates for various MCL options under consideration for the proposed rule. The comment period on the HRRCA ended on April 12, 1999, and EPA received approximately 26 written comments from a variety of stakeholders, including the American Water Works Association, the National Rural Water Association, the National Association of Water Companies, the Association of Metropolitan Water Agencies, State departments of environmental protection, State health departments, State water utilities and local water utilities.

Significant comments on the HRRCA addressed the topics of radon occurrence, exposure pathways, sensitive sub-populations and the risks to smokers, risks from existing radon exposures, risks associated with co-occurring contaminants, risk increases associated with radon removal, the benefits of reduced radon exposures, the costs of radon treatment measures, the cost and benefit results, and the Multimedia Mitigation (MMM) program. The following discussion outlines the significant comments received on the HRRCA and the Agency's response to these comments.

1. Radon Occurrence

Several commenters had concerns related to EPA's analysis of radon occurrence. Two commenters felt that the radon levels in Table 3.1 of the HRRCA were too low and not representative of radon occurrence in their regions. A California water utility indicated that due to limitations of the NIRS, EPA should conduct a new national radon survey, with special emphasis on determining radon levels in the largest systems, before promulgating the rule. Two commenters from Massachusetts expressed concerns about radon occurrence. One suggested that additional analysis of radon variability in individual wells was required, and another indicated that the effects of storage and residence time on radon levels in supply systems needed to be taken into account. One commenter indicated that EPA should more strongly consider that most risk reductions predicted in the HRRCA come from reductions in radon levels in the small proportions of systems with initial very high radon levels.

EPA Response 1–1

As part of the regulatory development process, EPA updated and refined its analysis of radon occurrence patterns in ground water supplies in the United States. This new analysis incorporated information from the EPA 1995 National Inorganic and Radionuclides Survey (NIRS) of 1000 community ground water systems throughout the United States, along with supplemental data provided by States, water utilities, and academic researchers. EPA's current re-evaluation used data from 17 States to determine the differences between radon levels in ground water and radon levels in distribution systems in the same regions. The results of these comparisons were used to estimate national distributions of radon occurrence in ground water. EPA believes that the existing NIRS data, along with the Agency's updates to this data, currently provide the most comprehensive *national-level* analysis of radon occurrence patterns in ground water supplies. This analysis is not intended for the estimation of radon occurrence at the state-level.

Variability within the NIRS radon occurrence data was analyzed for several important contributing factors: within-well (temporal) variability, sampling and analytical (methods) variability, intra-system variability (variability between wells within a single system), and inter-system variability (variability between wells in different systems). Several important conclusions were drawn from this analysis. First and foremost is the conclusion that the NIRS data do capture the major sources of radon occurrence variability and thus can be used directly, without any additional correction for temporal or sampling and analytical variability, to provide reasonable national estimates of radon levels and variability levels in ground water drinking supplies. In addition, EPA analyzed the additional data sets provided from stakeholders (described previously) in conjunction with the NIRS radon data to estimate the magnitudes of the variability sources. Based on all of these analyses, EPA has concluded that the variability between systems dominates the over-all variability (it comprises approximately 70 percent of the over-all variability). Temporal variability (13–18 percent), sampling and analytical variability (less than 1 percent), and intra-system variability (12–17 percent) are relatively minor by comparison. These results are discussed in detail elsewhere (USEPA 1999b).

Note: These estimates of variability sources apply to national-level radon occurrence estimates: individual regions may have systems that show variability sources that deviate significantly from these values.

This analysis of variability was incorporated into EPA's estimates of nation-wide radon occurrence and was used in its estimates of the effects of uncertainty in occurrence information on total national costs of compliance.

In response to the comment that ''most risk reductions predicted in the HRRCA come from reductions in radon levels in the small proportions of systems with initial very high radon levels'', EPA agrees that a system with high radon levels would benefit more from water mitigation than a system with much lower initial radon levels, but the vast majority of the national water mitigation benefits come from systems that are above the MCL, but not that high above it (*e.g.*, 80 percent removal required for the system to be at the MCL). This is true since radon is approximately log-normally distributed (i.e., a much higher percentage of water systems can be expected to have relatively low radon levels than relatively high radon levels) and hence *most systems* fall into this category. For this reason, the summation of these smaller per system benefits enjoyed by the large number of systems nearer the MCL greatly outweigh summation of the larger per system benefits enjoyed by the minority of systems with very high radon levels. This is demonstrated in Table 6–2 of the HRRCA (''Estimated Monetized Benefits from Reducing Radon in Drinking Water''), in which the central tendency estimate of monetized benefits associated with an MCL of 500 pCi/L is 212 million dollars and the benefits associated with an MCL of 100 pCi/L is 673 million dollars. This means that, in the latter case, 461 million dollars of the benefits come just from the systems with radon levels between 100 and 500 pCi/L (80 percent removal required), while the remaining benefits (212 million dollars) come from the systems with radon levels from 500 pCi/L up to the highest radon levels.

Five commenters indicated that the estimates of the numbers of entry points per system used in the HRRCA were incorrect, in that large systems had far more entry points than the numbers given in Table 5.4 of the HRRCA. Several of these commenters cited data from the Community Water System Survey (CWSS), showing higher numbers of wells per system in each system size category than were used for cost calculations in the HRRCA.

EPA Response 1–2

The relevant distribution for costing out non-centralized treatment is the number of entry points, not the number of wells. A given entry point (the point at which treatment is applied) may be fed by several wells, and hence there is a discrepancy in numbers between the HRRCA, which reported a distribution of entry points, and Table 1–5 of the Community Water System Survey (CWSS), which reported the average number of wells per system. These numbers are related, but not directly comparable. In general, the average number of entry points for a class of ground water systems would be expected to be smaller than the average number of wells. In the HRRCA, the distribution of entry points per system was estimated from a statistical analysis (''bootstrap analysis'') of the well and entry point data from the CWSS. This statistically-calculated distribution was then used to estimate the percentage of systems within a system size category having a given number of entry points. However, as part of its uncertainty analysis, EPA has used the 95% confidence upper bound of the site distribution in the national cost estimates supporting this proposal. The average number of entry points per system is roughly 10% higher using this upper bound analysis. In addition, to test the effects of varying this distribution on the national costs of compliance, the per system costs, and the per household costs, EPA conducted an uncertainty analysis (Monte Carlo analysis including sensitivity) on the distribution by simultaneously varying both the percentages of systems estimated to have a particular number of sites and the estimated number of sites. The results of this analysis are reported both in this notice and in the Regulatory Impact Analysis. It should be noted that the treatment unit costs and total number of systems dominated the cost uncertainty and that the entry point distribution was a relatively minor contributor to the overall cost uncertainty.

2. Exposure Pathways

A number of issues related to radon exposure pathways were raised. Several commenters indicated that the risks associated with the build-up of radon in carbon filters needed to be addressed in HRRCA. Concerns were also expressed about general population exposures to radon in air released from aeration facilities and exposures to workers at water utilities. Another commenter said that EPA should discuss the persistence of radon in the body after ingestion.

EPA Response 2–1

The risks from radon build-up in carbon filters and radon off-gas emissions are discussed in some detail in this notice, including an evaluation of risks, a discussion of references, and responses from a survey of air permitting boards about the permitting of radon off-gas.

EPA Response 2–2

The persistence of radon in the body following ingestion has been investigated and the results have been presented in the Criteria Document for Radon (USEPA 1999b). In brief, radon ingested in water is well-absorbed from the stomach and small intestine into the bloodstream and transported throughout the body. Radon is rapidly (within approximately one hour) excreted from the body via the lungs, so only about 1 percent of ingested radon undergoes radioactive decay while in the body. The risks from the retained radon and its decay products in various organs are calculated by NAS and adopted by EPA in the proposed rule.

3. Nature of Health Impacts

No comments were made concerning the general nature of adverse effects associated with radon exposure. Comments concerning specific aspects of health impact evaluation are summarized in the following sections.

(a) Sensitive subpopulations, risks to smokers, non-smokers. Comments on these sections are addressed together because the majority of the comments had to do with the characterization of smokers as a sensitive population. Several commenters noted that most risk reduction from reducing radon exposure occurs among smokers, and took the position that EPA should not include risk reductions to smokers in its benefits assessment, because smoking can be viewed as a voluntary risk. One commenter suggested that the smokers' willingness to pay for cigarettes also indicated a willingness to face the risk of smoking.

EPA Response 3–1

The term, ''groups within the general population'' is addressed, but not comprehensively defined, in the 1996 amendments to the Safe Drinking Water Act (SDWA, §′1412(b)(3)(C)). The definition of sensitive subpopulations is an issue for discussion and debate, and EPA is interested in input from stakeholders. The National Academy of Sciences (NAS) Radon in Drinking Water Committee, as part of their assessment of the risks of radon in drinking water, has considered whether groups within the general population, including smokers, may be at increased risk. The NAS Committee has indicated, in their Risk Assessment of Radon in Drinking Water report, that smokers are the only group within the general population that is more susceptible to inhalation exposure to radon progeny, but did not specifically identify smokers as a sensitive subpopulation.

In this proposal, EPA is basing its risk management decision on risks to the general population. The general population includes smokers as well as former smokers. The risk assessments for radon in air and water are based on an average member of the population, which includes smokers, former smokers, and non-smokers. A more complete discussion on the risks of radon in drinking water and air is presented in the NAS's risk assessment report and in Section XII of this preamble.

(b) Risk reduction model, risks from existing radon exposures. Commenters raised only one concern associated with the risk model used to estimate radon reduction benefits. Three commenters suggested that EPA should consider adopting a threshold-based model for radon carcinogenesis, and that EPA's current (non-threshold) approach overestimates radon risks. In support, the commenters cited a recently published paper (Miller et al, 1999) as providing evidence that a single alpha particle ''hit'' typical in low-level radon may not be sufficient to cause cell transformation leading to cancer.

EPA Response 3–2

There are a number of papers that have recently examined the effects of a single alpha particle on a cell nucleus of mammalian cells in culture. The authors of this study concluded that cells were more likely to be transformed to cancer causing cells if there were multiple alpha particle hits to their nuclei. However, another study, *Hei et al.* (1997), using a similar methodology, found direct evidence that a single ''particle traversing a cell nucleus will have a high probability of resulting in a mutation'' and concluded that their work highlighted the need for radiation protection at low doses. Moreover, follow-up microbeam experiments described by Miller et al. at the 1999 International Congress of Radiation Research demonstrated that one alpha particle track through the nucleus was indeed sufficient to induce transformation under some experimental conditions. Epidemiological data relating to low radon exposures in mines also indicate that a single alpha track through the cell may lead to cancer. Finally, while not definitive by themselves, the results from residential case-control studies provide some direct support for the conclusion that environmental levels of radon pose a risk of lung cancer. EPA has based its current risk estimates for radon in drinking water on the findings of the National Academy of Sciences. Rather than focus on the results of any one study, the NAS committees based their conclusions on the totality of data on radon—a weight-of-evidence approach.

Both the BEIR VI Report (NAS 1999a) and their report on radon in drinking water (NAS 1998b) represent the most definitive accumulation of scientific data gathered on radon since the 1988 NAS BEIR IV (NAS 1988). These committees' support for the use of linear-non-threshold relationship for radon exposure and lung cancer risk came primarily from their review of the mechanistic information on alpha-particle-induced carcinogenesis, including studies of the effect of single versus multiple hits to cell nuclei.

In the BEIR VI report (NAS 1999a), the NAS concluded that there is good evidence that a single alpha particle (high-linear energy transfer radiation) can cause major genomic changes in a cell, including mutation and transformation that potentially could lead to cancer. They noted that even if substantial repair of the genomic damage were to occur , ''the passage of a single alpha particle has the potential to cause irreparable damage in cells that are not killed.'' Given the convincing evidence that most cancers originate from damage to a single cell, the committee went on to conclude that ''on the basis of these [molecular and cellular] mechanistic considerations, and in the absence of credible evidence to the contrary, the committee adopted a linear-nonthreshold model for the relationship between radon exposure and lung-cancer risk. However, the BEIR VI committee recognized that it could not exclude the possibility of a threshold relationship between exposure and lung cancer risk at very low levels of radon exposure.'' The NAS committee on radon in drinking water (NAS 1999b) reiterated the finding of the BEIR VI committee's comprehensive review of the issue, that a ''mechanistic interpretation is consistent with linear, non-threshold relationship between radon exposure and cancer risk''. The committee noted that the ''quantitative estimation of cancer risk requires assumptions about the probability of an exposed cell becoming transformed and the latent period before malignant transformation is complete. When these values are known for singly hit cells, the results might lead to reconsideration of the linear no-threshold assumption used at present.'' EPA recognizes that research in this area is on-going but is basing its regulatory decisions on the best currently available science and recommendations of the NAS that support use of a linear non-threshold relationship.

(c)Risk and risk reduction associated with co-occurring contaminants. Several commenters addressed the issue of risks associated with co-occurring contaminants. Other commenters indicated a need to include risks and risk reductions from co-occurring contaminants.

EPA Response 3–3

The contaminants that may co-occur with radon that are of main concern are those that can cause fouling of aeration units (or otherwise impede treatment) and those that are otherwise affected by the aeration process in such a way as to increase risks. Measures and costs to avoid aeration fouling are discussed in this notice and in the references cited. Arsenic co-occurrence may be relevant since some systems may have to treat for both, but the treatment processes are not incompatible. In fact, the only side-effect of the aeration process that may impact the removal of arsenic would be the potential oxidation of some fraction of less easily removed As(IV) form to the more easily removed As(VI) form. There would be no additional costs due to this effect, and in fact, there may be cost savings involved. The potential for increased risks due to potential disinfectant by-product formation after disinfection, is discussed next.

(d) Risk increases associated with radon removal. Five commenters said that EPA should include quantitative estimates of the risk increases associated with increased exposure to disinfection byproducts (DBPs) in the risk and cost-benefit analyses of the HRRCA. One commenter said that risks should be apportioned appropriately between the proposed radon rule and the Groundwater rule. Another commenter maintained that, contrary to the assertion in the HRRCA, there would be no reduction in microbial risks due to the increased disinfection associated with the radon rule because most groundwater sources currently present no microbial risks.

EPA Response 3–4

EPA would like to highlight that the AMCL/MMM option is the preferred option for all drinking water systems, which would result in very few water treatment systems adding disinfection. EPA expects the radon rule to result in a minority of ground water systems choosing the MCL option, and of those, many will be larger systems. Since very few small systems are expected to choose the MCL option , very few systems are above the AMCL of 4000 pCi/L, and most large ground water systems already disinfect their water, few systems are expected to add disinfection in response to the radon rule, i.e., increased risk due to disinfection by-product formation should not be a significant issue. However, EPA does evaluate this risk-risk trade-off in this notice for that minority of systems that will be expected to add disinfection with treatment for radon. For that minority of systems, the trade-off between decreased risks from radon and increased risks from disinfection-by-products is favorable.

4. Benefits of Reduced Radon Exposure

The majority of the comments related to the estimation of benefits focused on the methods used to monetize reductions in cancer risks. There were also a few comments on non-quantifiable benefits, and on several other topics. The previous comments pertaining to risk reductions to smokers and that benefits from these risk reductions should be excluded from the HRRCA apply here as well.

(a) Nature of regulatory benefits. There were few comments on this section, most of which pertained to non-quantifiable benefits. One commenter indicated that the peace-of-mind non-quantifiable benefit from radon reduction would be offset by the anxiety of those living near aeration plants. Another noted that peace-of-mind benefits were not easy to quantify for non-threshold pollutants like radon and, in fact, that the regulation of radon might actually increase anxiety by drawing attention to the risks associated with radon exposures. Commenters also noted that claiming arsenic reduction as a benefit from aeration is questionable because there is no demonstrated correlation between the levels of radon and arsenic in groundwater systems.

EPA Response 4–1

By definition, non-quantifiable benefits cannot be measured and have not been measured in the HRRCA analysis. Thus, comparisons of types of such benefits are not very meaningful. EPA attempts to note these potential benefits when the Agency believes they might occur, as in the case of peace-of-mind benefits from radon reduction. There may also be non-quantifiable costs that may offset any non-quantifiable benefits. These include anxiety on the part of residents near treatment plants and customers who may not have previously been aware of radon in their water. As noted elsewhere in this preamble, EPA believes it unlikely that accounting for these non-quantifiable benefits and costs quantitatively would significantly alter the overall assessment.

(b) Monetization of benefits. Comments related to risk reduction have been discussed in previous responses, so are not discussed further here. Commenters addressed all three approaches to monetizing benefits: the value of statistical life; the costs of illness; and willingness-to-pay. A number of commenters suggested the use of Quality-Adjusted Life Years (QALY) as an alternative approach to the valuation of health benefits. One commenter indicated that the use of QALYs was a good way to avoid having to monetize health outcomes. Two commenters indicated that QALYs had the advantage of being able to take into account the delayed onset of cancer, as well as reduced incidence. One organization suggested QALYs as a superior method for combining the benefits from fatal and non-fatal illness over different time periods; which would be particularly useful in the case of smokers, whose cancers are likely to be delayed, but not necessarily prevented, by reductions in radon exposure.

EPA Response 4–2

The use of QALYs has been extensively discussed within EPA and also before the Environmental Economics Advisory Committee of EPA's Science Advisory Board. At this time, current Agency policy is to use Value of Statistical Life (VSL) estimates for the monetization of risk reduction benefits. EPA believes QALY calculations to be experimental and not well established for the types of analyses performed by the Agency.

(c) Value of statistical life (VSL). Several commenters questioned the use of, or the value selected for, the value of statistical life as a measure of benefits. Other commenters indicated that the large range of uncertainty associated with the estimates of risk reduction called the VSL (and the willingness-to-pay) methods into question, and indicated that EPA needed to better justify the central-tendency VSL value selected for use in the HRRCA. They maintained that the VSL approach would only be appropriate if the VSL estimates were derived from ''similar scenarios'' to those being evaluated in the HRRCA. Another commenter suggested that using the VSL was inappropriate in that the VSL dollars did not represent (as do compliance costs) actual resource losses to society that could be spent on other programs (e.g. pollution reduction). Thus, the comparison of compliance costs to VSL costs is not valid. They strongly recommend the use of compliance cost per life saved as an appropriate measure for judging radon control options. One commenter indicated that the use of the VSL approach resulted in greatly over-estimated benefits of radon exposure reduction, particularly because the VSL for smokers is the same as for non-smokers and does not account for the age at which mortality is avoided. Another questioned the validity of the mean VSL value used in the HRRCA, and indicated that VSL estimates should only come from the peer-reviewed scientific literature or from Agency documents that had been subject to public comment.

EPA Response 4–3

The VSL value, currently recommended by Agency guidance, is derived from a statistical distribution of the values found in twenty-six VSL studies, which were chosen as the best such studies available from a larger body of studies. This examination of studies was undertaken by EPA's Office of Air and Radiation in the course of its Clean Air Act retrospective analysis. EPA believes the VSL estimate ($5.8 million, 1997 dollars) to be the best estimate at this time, and is recommending that this value be used by the various program offices within the Agency. This estimate may, however, be updated in the future as additional information becomes available to assist the Agency in refining its VSL estimate. The VSL estimate is consistent with current Agency economic analysis guidance, which was recently peer reviewed by EPA's Science Advisory Board.

d. Costs of illness (COI). Two commenters suggested that EPA should further review the literature on the costs of illness and develop better cost measures for the illnesses addressed in the HRRCA.

EPA Response 4–4

EPA believes that the COI data is the most complete analysis of this type currently underway. The cost of illness (COI) data shown in the HRRCA were presented as a comparison to Willingness to Pay (WTP) to avoid chronic bronchitis. The Agency did not use the COI data to estimate risk reduction valuations for non-fatal cancers because these estimates can be seen as underestimating the total WTP to avoid non-fatal cancers. COI may understate total WTP because of its failure to account for many effects of disease such as pain and suffering, defensive expenditures, lost leisure time, and any potential altruistic benefits. It is important to note that the proportion of benefits attributable to non-fatal cancer cases accounts for less than one percent of the total benefits in the HRRCA.

(e) Willingness-to-pay. Several commenters questioned EPA's use of the willingness-to-pay (WTP) approach for monetizing non-fatal cancer risk reductions. Another suggested that a WTP value for victims of non-fatal cancers should have been used, instead of the WTP estimates for chronic bronchitis. It was also suggested that WTP measures would vary within the general population, and that use of a constant value was inappropriate.

EPA Response 4–5

EPA believes that the WTP estimates to avoid chronic bronchitis are the best available surrogate for WTP estimates to avoid non-fatal cancers. WTP estimates were used in the HRRCA as opposed to COI to value non-fatal cancer cases. EPA believes that COI may understate total WTP because of its failure to account for many effects of disease such as pain and suffering, defensive expenditures, lost leisure time, and any potential altruistic benefits. It is important to note that the proportion of benefits attributable to non-fatal cancer cases accounts for less than one percent of the total benefits in the HRRCA.

(f) Treatment of benefits over time. Many commenters objected to EPA's assumption that cancer risk reduction, and hence benefits, would begin to accrue immediately upon the reduction of radon exposures. In addition, they felt that the failure to discount health benefits resulted in an overestimation of the benefits. One commenter suggested that a ''gradual phase-in'' of risk reduction should be incorporated into the HRRCA benefits calculation. It was also suggested that an alternative to immediate benefits accrual be used, and that the effects of the immediate benefits accrual assumption be discussed in detail with regard to the uncertainties it introduces into the benefits estimates. One commenter identified the assumption of immediate benefits as a major source of benefits overestimation. Another comment asked that EPA provide better justification for assuming immediate benefits accrual, and suggests instead that a linear phase-in of risk reduction over 70 years would be more appropriate. Three commenters also indicate that the failure to take latency of risk reduction into account and to discount benefits appropriately, greatly biases the benefits estimates in the upward direction. One commenter indicated that the failure to discount benefits resulted in a five- to ten-fold over-estimation.

EPA Response 4–6

These comments address the issue of latency, the difference between the time of initial exposure to environmental carcinogens and the onset of any resulting cancer. Qualitative language has been added to the preamble regarding adjustments, including latency, that could be made to benefits calculations. This qualitative discussion notes that latency is one of a number of adjustments related to an evaluation of potential benefits associated with this rule. EPA believes that such adjustments should be considered simultaneously. For further discussion, see section XIII.D of the preamble.

5. Costs of Radon Treatment Measures

(a) Drinking water treatment technologies and costs. All of the commenters had concerns related to EPA's assumptions and analyses of costs of radon treatment measures. In fact, one commenter suggested that the entire section was oversimplified by EPA. Most of the commenters, however, provided more specific comments which are outlined next.

EPA Response 5–1

Most, if not all, commenters assumed that EPA would propose that the risks from radon would be best addressed by drinking water systems attempting to meet the MCL. Under this scenario, many small systems would be in situations where they faced very difficult treatment issues, often with technically difficult and/or expensive solutions. However, EPA is suggesting that the risks from radon are best addressed by the combined use of the AMCL with a multi-media mitigation (MMM) program. Since the proposal also includes a regulatory expectation of adoption of the AMCL by small systems, EPA believes that many of the comments received are less applicable to this proposal than if the MCL were the preferred route of compliance.

(b) Aeration. Several commenters expressed concerns related to aeration costs. One major concern was EPA's failure to address worker safety issues, and the associated cost of occupational safety programs, at treatment plants. A reference to earlier studies of increased risk to neighbors is provided, but details are not included to evaluate these studies. Concern was expressed that costs for permitting and control of radon emissions from treatment plants were not included, and that the public might react strongly to the presence of a local treatment plant even if analysis showed the risk to be minimal. Three commenters noted that the HRRCA failed to consider quantifiable corrosion control costs associated with aeration. Installation of aeration for radon removal may also affect lead/copper levels in the water distribution system, resulting in additional treatment modifications and costs. Many systems will have to develop a different corrosion control strategy to comply with the lead and copper rule due to the radon regulation.

EPA Response 5–2

Worker safety issues for aeration treatment of radon in drinking water are discussed in today's notice (Section

VIII.A.3) and are discussed in more detail in other sources (USEPA 1994b, USEPA 1998h). Radon exposure to workers in drinking water treatment plants has been discussed in the literature (e.g., Fisher et al. 1996, Reichelt 1996). In fact, these discussions usually apply to situations where radon is NOT the contaminant being purposely removed, since there is currently no regulatory driver to do so. When ground water is exposed to air during treatment for any contaminant, radon may be released and may accumulate in the treatment facility. The National Research Council (NAS 1999b) suggests that the air in all groundwater facilities *treating for any contaminant* should be monitored for radon and that ventilation should be investigated as a means of reducing worker exposure. In support of this position, EPA would further strongly suggest that systems that attempt to meet the MCL (i.e., that are in States that do not adopt the AMCL or otherwise choose to meet the MCL) by installing aeration treatment should take the appropriate measures to monitor and ventilate the treatment facilities. For those small systems that choose GAC treatment, other precautions should be taken to monitor and control gamma exposure. GAC treatment issues are discussed later in this notice and are discussed in detail elsewhere (USEPA 1994b, AWWARF 1998 and 1999).

EPA has suggested that occupational exposures be limited to 100 mRem/year, a level well below the upper limit of 5000 mRem/year approved in by the President in 1987 (''Radiation Exposure Guidance to Federal Agencies for Occupational Exposure'', as cited in USEPA 1994b). Based on limited data, it appears that 100 mRem/year is a maintainable objective within water treatment plants treating for radon or other contaminants. Exposure level monitoring and mitigation through a combination of air monitoring and ventilation has been demonstrated to be feasible and relatively inexpensive (e.g., Reichelt 1996).

Regarding the effects on water corrosivity and the impacts of costs of corrosion control measures, this notice presents much more detail on EPA's assumptions. Corrosion control measures are included in national cost estimates and are discussed in this notice. Case study information on corrosion control costs associated with aeration are included in the Radon Technologies and Costs document (USEPA 1999h).

(c) GAC. Two commenters noted that the option for use of granular activated carbon (GAC) did not address potential problems with radioactivity buildup in the carbon. In consideration of treatment methods the two commenters saw no mention of the cost of disposal of GAC used for radon removal. If not replaced in time it will become a low level radioactive waste because of Lead 210 and will become difficult to dispose of. Other issues that need to be addressed include: will the unit require special shielding; may the charcoal bed be required to have a radioactive materials license from the State; and how may radioactive carbon be disposed of?

EPA Response 5–3

Special considerations regarding GAC operations, maintenance, and ultimate GAC unit disposal are discussed in some detail in Section VIII.A of this notice, including discussions of the radiation hazards involved and steps that can be taken to ameliorate these hazards. GAC disposal costs are included in the operations and maintenance costs in the model used for cost estimates. Comparisons of modeled GAC capital and operations & maintenance cost estimates to actual costs reported in case studies are included in Section VIII of this notice. EPA would like to strongly emphasize that carbon bed lifetimes (carbon bed replacement rates) should be designed to preclude situations where disposal becomes prohibitively expensive or technically infeasible.

Recently, the American Water Works Association Research Foundation has published a study on the use of GAC for radon removal, which includes discussions of the issues described previously, that concludes that GAC is a tenable treatment strategy for small systems when used properly under the appropriate circumstances (AWWARF 1998a). AWWARF also reviewed the proper use of GAC for radon removal in its recent review of general radon removal strategies (AWWARF 1998b). When the final radon rule is promulgated, a guidance manual will be published describing technical issues and solutions for small systems installing treatment.

One commenter suggested that the costs for GAC seemed to be too high. The figures used in the analysis could be two orders of magnitude above the costs actually seen by the systems.

EPA Response 5–4

EPA agrees that its GAC cost estimates seem to be very high, as compared to case studies (USEPA 1999h, AWWARF 1998b). EPA agrees with others (e.g., AWWARF 1998a and b) that GAC will probably be cost-effective for very small systems or in a point-of-entry mode. This issue is addressed in the preamble (Section VIII.A) and GAC will be included as a small systems compliance technology.

(d) Regionalization. Two commenters questioned a cost of $280,000 as the single cost for regionalization. Assuming $100/foot for an interconnection, these costs would equate to an interconnection of 2800 feet which seems low. Systems are usually separated by more than one-half mile. A range of costs may need to be considered rather than a single number. Smaller systems will have smaller costs, while large systems will have larger costs. Thus, the charge for regionalization should vary by systems size. Also, EPA should clarify whether or not regionalization charges include yearly operation and maintenance costs.

EPA Response 5–5

EPA agrees that the costs of regionalization would be expected to change with water system size, but, as indicated in the assumptions outlined in the February 26, 1999 HRRCA, EPA assumed that only very small systems (those serving fewer than 500) would resort to regionalization in response to the radon rule. Given that the proposed rule involves a multi-media approach that greatly encourages small systems to choose the AMCL of 4000 pCi/L in conjunction with a multi-media mitigation program, EPA expects that very few systems would choose regionalization as an option. EPA believes that the assumption that 1 out of 100 small systems that choose the MCL option would regionalize is conservative and would only be exercised if regionalization were cost-competitive with other options, except under very unusual circumstances. Since the estimate of $250,000 is much more expensive than any other option modeled for those size categories, this assumption supports the situation where small systems may be expected to entertain this option, i.e., where regionalization does not involve piping water over great distances. This figure is based on a simple estimate using the cost of installed cast iron pipe at $44 per linear foot (an average cost for several pipe relevant pipe diameters) from the 1998 Means Plumbing Cost Data and applying 20 percent for fittings, excavation, and other expenses to arrive at an estimate of $53 per linear foot, or $280,000 per linear mile. Purchased water costs ($/kgal) were assumed to equal the pre-regionalization costs of production ($/kgal), merely as a modeling convenience. In some cases, purchased water costs may be higher, in some cases lower. Although EPA does not have many case studies to support this assumption, it does have information on a Wisconsin case study in which a small water system (serving 375 persons) regionalized to connect to a near-by city water supply in 1995, partly in response to a radium violation. The capital costs for this regionalization case study was $225,000. There were no reported operations costs associated with the purchased water. EPA makes no claims that this case study is typical, but rather that this is the best assumption that it could make based on the available information. Since this is a minor part of the over-all national costs and since a more extensive modeling of the costs of regionalization would necessitate a much more detailed modeling of the additional benefits of regionalization (which were not included), this assumption is maintained in the Regulatory Impact Assessment for this proposed rule.

One commenter also questioned the feasibility of regionalization for many systems. There are very few locations where this is possible and just hooking up to a larger supplier is not practical. Many have systems that are not acceptable to a larger supplier and many larger suppliers won't accept the liability involved in taking over the small system.

EPA Response 5–6

Since most small systems are expected to adopt the AMCL/MMM option, EPA's regionalization assumption (1 percent of the minority of small systems that choose the MCL option) is consistent with this commenter's concern. Nevertheless, administrative regionalization is often feasible, in particular when this does not require new physical connections, and may be an important element of the long term compliance strategy for a number of systems.

(e) Pre-treatment to reduce iron/manganese levels. The majority of the commenters disagreed with EPA's assumptions on the removal of Fe/Mn. It was assumed that essentially all systems with high Fe/Mn levels are likely to already be treating to remove or sequester these metals. Therefore, costs of adding Fe/Mn treatment to radon removal were not included in the February, 1999 HRRCA (64 FR 9560). Commenters suggested that this is a poor cost assumption, in that there are many systems above the secondary MCL for Fe/Mn that do not treat. Of those that sequester, commenters suggested that existing treatment is ineffective once Fe/Mn has been oxidized. Therefore, filtration as well as disinfection would be required for that type of system at a significant additional cost that needs to be considered when reviewing the HRRCA.

If Fe/Mn is present in the source water, removal treatment will be necessary to prevent fouling of the radon removal system. Disposal for the Fe/Mn residuals also presents a special problem with its associated costs. One commenter noted that by not including the costs of Fe/Mn removal, EPA is making a poor assumption and may be underestimating costs.

EPA Response 5–7

EPA recognized that not quantifying the costs associated with the control of dissolved iron and manganese (Fe/Mn) was potentially a poor assumption, and indicated that this assumption would be revisited for the Regulatory Impact Analysis supporting this proposed rule. However, EPA also indicated that national costs and average per system costs would probably not be significantly affected in addressing this issue. While EPA's current modeling results support this conclusion, EPA has included the costs of adding chemical stabilizers (which minimize Fe/Mn precipitation and also provide for corrosion control in some cases) by 25 percent of small systems that treat and 15 percent of large systems that treat. A more detailed discussion on the inclusion of Fe/Mn treatment costs is provided in Section VIII of the preamble.

To further support its position on Fe/Mn control, EPA has also (1) analyzed case studies of systems aerating, which include Fe/Mn control measures for a small minority of the systems, (2) performed an analysis of the co-occurrence of radon with Fe/Mn in ground water, and (3) performed an uncertainty analysis on costs, which includes a simulation of more expensive control measures for Fe/Mn. All of these results are also discussed in Section VIII of the preamble.

(f) Post treatment-disinfection. Many commenters stated that EPA's assumption that the majority of groundwater systems already disinfect is false. Some commenters felt this is inconsistent with the Ground Water Rule estimates. Commenters suggested that analyses supporting the proposed groundwater rule estimate that only 50 percent of CWSs and only 25 percent of NTNCWSs disinfect, while Table 5–2 of the HRRCA suggests that the majority of water systems using groundwater already disinfect and that 20 percent of all water systems serving 3,300 or greater have aeration or disinfection in place.

EPA Response 5–8

The cited analyses supporting the Ground Water Rule (GWR) were conducted using occurrence estimates at the level of individual entry points at water systems. The February 1999 Radon HRRCA was conducted using occurrence estimates at the level of water systems. The GWR and radon analyses use the same data source for estimating their respective disinfection-in-place baselines, the 1997 Community Water System Survey (USEPA 1997a), the only source of information of this type that is based on a survey that was designed to be statistically representative of community water systems at the national level. The GWR used a disinfection-in-place baseline for entry points and the radon HRRCA used a disinfection-in-place baseline for water systems.

The most desirable level of analysis is at the entry point, but the only nationally representative data source for radon, the National Inorganics and Radionuclides Survey, was conducted at the water system level (samples were taken at the tap), which provides no information about radon occurrence at individual entry points within water systems. Radon intrasystem (within system) occurrence variability studies were not available for the analyses supporting the February 1999 radon HRRCA. In the interim between publishing the radon HRRCA and today's proposal, EPA has conducted radon intrasystem variability studies (based on studies other than NIRS) and has used the results of this study to estimate radon occurrence at the entry point level. The current Regulatory Impact Analysis supporting the Radon rule was conducted at the entry point level, consistent with the Ground Water Rule.

EPA Response 5–9

The additional costs to which this commenter is referring, namely the costs of storage for contact time, are included in the costs of the clearwell, which are included in the costs of the aeration process. In the scenarios in which disinfection is assumed, EPA does NOT assume that the systems have a clearwell in place and does include the costs of adding a clearwell for collection of water after aeration and for five minutes of disinfection contact time, which EPA believes to be sufficient for 4-log viral de-activation.

(g) Monitoring costs. One commenter expressed concerns regarding EPA's calculation of monitoring costs. The commenter suggested that EPA grossly underestimated the number of wells per

different water system size in Table 5.4 of the HRRCA (64 FR 9585), page 9585 and in Appendix D of the HRRCA. As a result, monitoring costs need to be recalculated by EPA.

EPA Response 5–10

See EPA Response 1–2 for EPA's approach to determining the number of wells per system.

(h) Choice of treatment responses. As noted previously in Section G, one commenter questioned whether chlorination would always be the disinfection technology of choice, as well as EPA's assumption that existing chlorination practices would not have to be augmented if aeration were installed. Other commenters on cost issues questioned the feasibility and practicability of some technologies on cost grounds.

EPA Response 5–11

EPA assumed that chlorination would be the ''typical'' disinfection technology chosen to model the ''average treatment costs'' (or ''central tendency costs''). There is no way to know beforehand exactly how the universe of water systems will behave in response to a given situation, so EPA believes that the best way to model national compliance costs is to estimate these central tendency costs, then to use statistical tools to capture the fact that ''real world costs'' will spread around the central tendency costs, rather than being equivalent to them. By estimating the central tendency costs and using statistical uncertainty to capture ''real world'' variability (including variability in disinfection costs), EPA believes that this modeling technique allows for the fact that real systems will behave in a variety of ways, including things like choosing different disinfection technologies.

(i) Site and system costs. A number of issues were raised concerning site and system cost estimates. Several commenters suggested that the HRRCA severely underestimated the number of sites per system, citing the difference between the CWSS data and HRRCA assumptions. Several commenters noted that the numbers of sources per system in Table 5–4 of the HRRCA for systems serving 10,001—50,000 were too low. One commenter maintained that the number of sources per system could have a significant impact on national treatment costs.

EPA Response 5–12

EPA agrees that the distribution of the number of sites per system was underestimated and *has revised its estimate to be consistent with the CWSS.* However, it should be noted that while the distribution of the sites per system actually does have an impact on national treatment costs, this impact is significantly mitigated by the fact that the flow per well being treated decreases proportionally as the estimated number of wells per system increases.

(j) Aggregated national costs. Several commenters agreed that the national average costs masked significant impacts on small systems. When small systems are considered, the financial impact is large; in some cases, water bills could double or triple. Providing individual system costs is critical so that utilities can explain to their customers the specific costs and benefits for that specific system.

EPA Response 5–13

EPA estimates household impacts for small systems that install treatment (per household costs) by estimating the costs that small systems would face (per system costs), then spreading these costs over the customer base (population served). As demonstrated in the HRRCA, household costs for small systems are expected to be many times higher for very small systems than for larger systems. In listing small systems compliance technologies for radon, EPA estimated the impacts on small systems by estimating the per system costs and the per household costs and comparing them to affordability criteria, as described in this notice and in the references cited. However, it should also be noted that the vast majority of small systems are expected to comply with the AMCL/MMM option, rather than the MCL option. Under these circumstances, less than 1 percent of small systems would have to take measures to reduce radon levels in their drinking water.

(k) Costs to CWSs. Small systems will bear a significant percentage of the costs for implementing a radon MCL, but will only accrue a small proportion of the benefits. At the 300 pCi/L, the two categories of smallest systems combined would receive 5.6 percent of the benefits at this level, but would pay 42 percent of the total costs. Several commenters indicated that the benefit-cost ratio for small systems was thus highly unfavorable.

EPA Response 5–14

EPA recognizes that small systems experience similar benefits per customer as large systems, but, due to economies of scale (higher treatment costs per gallon treated), experience much higher costs per customer compared to large systems. This, of course, leads to higher costs at the same level of benefits. However, EPA has also recognized that radon is a multi-media problem in which most of the risk is presented from sources other than drinking water and has addressed this fact by designating the AMCL/MMM option as the preferred option for small systems. This will greatly lower the per customer costs faced by small systems and may lead to greater total benefits that accrue to small systems.

(l) Costs to consumers/households. One commenter thought that the household consumption presented in the HRRCA (83,000 gal/year) is too low. This is an understatement because treatment would be required for all water produced, not just water consumed by households.

EPA Response 5–15

EPA does not assume that per system costs are based only on residential water use and so does not miscalculate water *prices* in the way described by the commenter. To determine the price of water, EPA calculates per system costs based on both residential and non-residential consumers (which is the main reason EPA calculates costs for privately-owned and publically-owned separately, i.e., because they have different ratios of residential to non-residential consumption). These per system costs determine the costs per gallon *treated* (not per gallon *consumed*) to determine the water price. The water price may then be used in conjunction with the household consumption to estimate the water bills faced by households, since they do pay by the gallon consumed (and not by the gallon treated).

(m) Application of radon related costs to other rules. Several commenters addressed the need to include the cumulative impact of regulations in the RIA. The incremental costs of the regulations for radon, arsenic, and groundwater systems could substantially change the affordability analysis for small systems. Thus, treatment decisions need to be made with an understanding of all the requirements that must be met so that treatment systems can be designed to meet all requirements. One commenter suggested a multi-rule cost and benefit analysis to capture the true costs incurred by these systems.

EPA Response 5–16

The cumulative effects of rules are captured in EPA's ''affordability criteria'', which are described in the publicly available 1998 EPA document, ''National-Level Affordability Criteria Under the 1996 Amendments to the Safe

Drinking Water Act'' (USEPA 1998e). These small system affordability criteria take into account how much consumers are currently paying for typical water bills. Since the upcoming regulations will affect these amounts, the cumulative effect of the costs of the rules will be explicitly considered in the affordability determinations for small systems as new rules are issued. EPA recognizes that its method of basing affordability determinations on average costs does not address the situation of systems that have significantly above average costs because they must treat for a number of contaminants simultaneously. EPA believes this approach is consistent with the requirements of SDWA for identifying affordable small system technologies and notes that other SDWA mechanisms may be used to address situations where systems incur considerably higher costs.

6. Cost and Benefit Results

The main concern of many of the comments regarding this section suggested that the costs of controlling radon in drinking water far outweighed possible benefits, especially for small systems. Controlling indoor air radon was identified as a better use of regulatory and economic resources by several commenters. Commenters also had concerns regarding how national total costs, benefits, and economic impacts were calculated, and regarding the uncertainties in costs and benefits estimates.

(a) Overview of analytical approach. Many commenters indicated that the cost-benefit analysis was skewed toward overestimating benefits, and/or omitted important cost elements. One concern shared by many of these commenters was that the cost-benefit calculations were biased because mitigation costs, but not health benefits, were discounted. A commenter also indicated that too many assumptions had been used to derive cost and benefit estimates.

EPA Response 6–1

The radon cost benefit analysis was performed according to EPA guidelines, in an attempt to fairly portray both costs and benefits, and not leave out important categories of either costs or benefits.

Annual mitigation costs are compared to annual benefits for the cost benefit comparisons. Annual mitigation costs consist of annualized capital costs plus yearly operating costs. Annualized costs are computed under the assumption that capital expenditure are made up front, with borrowed funds, and the payments are then annualized over a period of twenty years. Changes in the rate of interest used in the annualization process will change the annual cost, just like a mortgage will change with different rates of interest. Adding yearly operating costs for one year to annualized capital costs for one year gives the total annual cost for the year. The issue of discounting of benefits is discussed in Section XIII.D.

In any modeling process, assumptions must be made. To model costs and benefits, assumptions about those costs and benefits must be made. The number of assumptions needed depends on the complexity of the problem addressed, and the time and information available to address it. We would be interested in information that might inform our modeling, particularly addressing improvements that could be made to specific assumptions.

(b) MCL decision-making criteria. A commenter requested that EPA define explicit decision-making criteria for setting MCL levels, to assure that the net benefit to society is positive.

Another commenter indicated that, because drinking water radon accounts for a small portion of total risks, EPA should consider the relative costs and benefits of mitigation on a case-by-case basis at individual systems before making regulatory decisions. A commenter suggested that if the latency of cancer risk reduction and benefits were discounted properly, the national cost-benefit ratios for radon mitigation would be between 5:1 and 9:1. They stated that EPA should not promulgate a rule with net negative benefits, especially in light of the large economic impacts on small systems.

A commenter indicated that the cost-benefit ratios in Table 6–13 of the HRRCA imply that regulation of radon in ground water is not justified. They point out that systems serving 25–3,300 people incur at least 56 percent of the costs and generate at most 21 percent of the total benefits at all MCLs. They say that justifying radon control in drinking water by adding in the benefits of MMM programs is not justified. Another commenter also maintained that the small, localized benefits of controlling radon exposures do not come near to justifying the costs of mitigation.

One commenter said that the decision to set an MCL must take into account the level of uncertainty in cost and benefit estimates. Another commenter suggested that the Agency undertake a quantitative uncertainty analysis of the cost and benefit estimates. Two commenters said that the closeness of the cost and benefit estimates should be considered in setting a regulatory level; if uncertainty is large, a less stringent MCL would be justified.

EPA Response 6–2

EPA has included a detailed discussion on its decision-making criteria for setting the MCL for radon in drinking water in the preamble for the proposed rulemaking (see Section VII.D).

(c) National costs of radon mitigation. Two commenters indicated that the national cost estimates obscured the high costs that would be borne by individual systems. One commenter indicated that radon variability in individual wells increases the uncertainty in the cost estimates. Another commenter said that cost estimates should include the costs of more frequent lead and copper exceedences brought about by increased aeration. Other comments on specific cost elements were summarized in Section 5. One commenter requested that EPA regionally disaggregate cost and benefit estimates because of structural and operational differences among water systems. Another commenter suggested that EPA should conduct a more comprehensive analysis of costs and benefits, including cost elements not currently addressed, such as waste management.

EPA Response 6–3

The national costs include an uncertainty analysis which captures the regional spread in treatment costs. In addition, EPA has estimated total national costs by assuming that most systems will face ''typical costs'', but that some will face ''high side'' and some ''low side'' treatment costs. These ''high side'' and ''low side'' cost differences are largely based on regional considerations, like the costs of land, structure, and permitting.

(d) Incremental costs and benefits. One commenter indicated that the incremental costs and benefits of the various MCL options should be presented in the HRRCA. They question the affordability of radon mitigation for small systems.

EPA Response 6–4

EPA has provided an analysis of the incremental costs and benefits of each MCL option in the HRRCA. See Table 6–7, Estimates of the Annual Incremental Costs and Benefits of Reducing Radon in Drinking Water, in the February 1999 HRRCA.

(e) Costs to community water systems. One commenter said that a more accurate picture of costs and impacts (inclusive of State and local costs) would be needed to make a reasonable

risk management decision. Another commenter suggested that EPA should consider the cumulative costs of all drinking water regulations on drinking water systems.

EPA Response 6–5

See EPA Response 5–14 for EPA's approach to determining the costs to CWSs. Administrative costs to States were not included in the February 1999 HRRCA, but have been added in the RIA for the proposed rule.

(f) Costs and impacts on households. One commenter asked that EPA explain how it determined what was an ''acceptable'' percentage of household income that would go to radon mitigation. Another commenter indicated that household costs should be compared to benefits at the local, rather than national, level, because benefits and costs are realized locally. A commenter indicated the median household incomes for households served by different system sizes are not shown; they also suggested that household costs as a percentage of income were underestimated in Table 6–11 of the HRRCA. One commenter said that expressing household impacts as a proportion of annual income trivializes it and that costs could more meaningfully be compared to other types of household expenses (i.e., food, rent). Several commenters also noted the significant impact the costs could have on customer water bills for small systems.

EPA Response 6–6

See EPA Response 5–15 for EPA's approach to determining the costs to households.

(g) Summary of costs and benefits. Comments from one organization regarding the cost-benefit comparison for radon mitigation were typical of those received from other sources. They cited the NRC/NAS report as indicating that only two percent of population risk came from drinking water and questioned whether the high costs of the rule could justify the small benefits obtained. They said that the cost-benefit comparison did not justify regulating radon in ground water, especially in small systems, where costs were highest and benefits lowest. Another commenter also pointed out that it would be more cost-effective to regulate radon in indoor air than in drinking water and further maintained that spending resources to mitigate radon in water could actually result in reduced public health protection. They point out that the cost-benefit ratios for the smallest systems range from 20:1 to 50:1, and suggest that these ratios, rather than the greater aggregate costs to large systems, should be persuasive in regulatory decision making. Other commenters suggested the high cost-benefit ratios did not justify the regulation of small systems.

EPA Response 6–7

The 1996 Safe Drinking Water Act Amendments require EPA to propose a regulation for radon in drinking water by August 1999. The options for small systems, proposed for public comment in this rulemaking, represents EPA's efforts to address stakeholder comments concerning small systems.

7. Multimedia Mitigation Programs

(a) Multimedia programs. Two commenters indicated that setting the AMCL at 4,000 pCi/L was justifiable. They suggested that EPA should utilize on MMM approach as the primary tool for reducing radon risks, and not use the SDWA to force the States to develop MMM programs.

Several commenters noted that the MCL EPA selects should be justifiable on cost-benefit grounds, with the MMM program serving as a supplemental program to allow States to achieve greater risk reduction at less cost. Another commenter suggested the multimedia approach allowed under the 1996 amendments to the SDWA should not be used with regard to radon–222 in water.

EPA Response 7–1

The requirement for implementation of an EPA-approved MMM program in conjunction with State adoption of the AMCL is consistent with the statutory framework outlined by Congress in the SDWA provision on radon. As proposed, States may choose either to adopt the MCL or the AMCL and an MMM program. EPA recommends that small systems comply with an AMCL of 4,000 pCi/L and implement a MMM program. See section VII.D for background on the selection of the MCL and AMCL.

Two commenters believe the radon regulation may result in litigation against water utilities, local, and State governments if systems comply with the AMCL rather than the MCL. As a result, some water utilities could choose to comply with the more stringent MCL rather than face potential litigation for meeting a ''less stringent standard,'' regardless of the increased public health protection. According to one commenter, problems will arise when both the AMCL and the MCL are required to appear on the annual Consumer Confidence Report. The public will view the AMCL as an attempt by the water industry to get around the MCL. This will leave the water utility vulnerable to toxic tort lawsuits. Because of these problems, the concept of an MMM program/AMCL is not as attractive as it once appeared.

EPA Response 7–2

EPA is aware of this concern and the risk communication challenges of two regulatory limits for radon in drinking water. However, the SDWA framework requires EPA to set an alternative maximum contaminant limit for radon if the proposed MCL is more stringent than the level of radon in outdoor air. It is important to recognize that in State primacy applications for oversight and enforcement of the drinking water program, States choosing the MMM approach will be adopting 4,000 pCi/L as their MCL. In addition, as part of the proposed rule, EPA will be amending the Consumer Confidence Reporting Rule to reflect the proposed regulation for radon. Under § 141.153 of the proposed radon rule, a system operating under an approved multimedia mitigation program and subject to an Alternative MCL (AMCL) for radon must report the AMCL instead of the MCL whenever reporting on the MCL is required.

Another commenter questioned the need for regulating radon in water below 3,000 pCi/L, and maintained that there is no conceivable reason to regulate it at 100 pCi/L, with or without an MMM program.

EPA Response 7–3

See EPA Response 6–2 for EPA's decision criteria for setting an MCL.

(b) Implementation scenarios evaluated. One commenter feels that a ''desk top review'' of States likely to adopt an MMM program would give more useful estimates of MMM acceptance than the HRRCA assumptions of zero, 50 percent, and 100 percent adoption of MMM programs. This commenter felt that for an MMM program to be productive, two things are necessary: (1) relatively high radon concentration in water and (2) relatively high radon in indoor air.

EPA Response 7–4

For the purposes of the HRRCA, EPA made these assumptions as a straight forward approach for assessing overall cost implications of MMM. States are not required to make their determinations on whether to adopt the MMM approach until after the rule is final in August 2000. Therefore, EPA did not have this information available when developing the HRRCA, nor does EPA have this information at this time. However, discussions with many State drinking water and radon program staff suggest that many States are seriously considering the MMM approach.

EPA expects that MMM programs will be able to achieve indoor radon risk reduction even in areas of low radon potential. It is important to keep in mind that the only way to know if a house has elevated indoor radon levels is to test it. Many homes in low radon potential areas have been found with levels well above EPA's action level of 4 pCi/L, often next door to houses with very low levels. EPA estimates that about 6 million homes in the U.S. of the 83 million homes that should test are at or above 4 pCi/L. To date only about 11 million homes have been tested. In addition, EPA is not requiring State MMM program plans to precisely quantify equivalency in risk reduction between radon in drinking water and radon in indoor air.

(c) Multimedia mitigation cost and benefit assumptions. Two commenters indicated that, even if it is not known how the MMM programs will be funded, the costs of administering such programs should be included in the HRRCA. Several commenters expressed concerns regarding the estimated cost of $700,000 per fatal cancer averted. One commenter felt that using this value is far too optimistic, indicating that the cost of radon risk reduction under State-mandated MMM programs will significantly exceed present costs under the voluntary system. To get the greatest risk reductions at the lowest costs, MMM program should focus on the houses with the highest radon concentrations. Another commenter recommended that EPA develop an MMM program that is better than the existing voluntary programs and further reduces the cost per fatal cancer avoided. The commenter also requested that EPA supply background information supporting use of this single MMM program cost estimate.

EPA Response 7–5

EPA is required under the UMRA to assess the costs to States of implementing and administering both the MCL and the MMM/AMCL. EPA has addressed these costs in the preamble of the rule.

EPA believes that the criteria for EPA approval of State MMM program plans will augment and build on existing State indoor radon programs and will result in an increased level of risk reduction.

As part of developing the 1992 ''A Citizen's Guide to Radon,'' EPA analyzed the risk reductions and costs of various radon testing and mitigation options (USEPA 1992b). Based on these analyses, a point estimate of the average cost per life saved of the current national voluntary radon program was used as the basis for the cost estimate of risk reduction for the MMM option. EPA had previously estimated that the average cost per fatal lung cancer avoided from testing all existing homes in the U.S. and mitigation of all those homes at or above EPA's voluntary action level of 4 pCi./L is approximately $700,000. This value was originally estimated by EPA in 1991. Since that time there has been an equivalent offset between a decrease in testing and mitigation costs since 1992 and the expected increase due to inflation in the years 1992–1997.

One commenter stated that experiences in Massachusetts showed that the costs of incorporating passive radon resistant construction techniques is about the same as current prices for marginal quality (active) radon mitigation in existing buildings, and disputed the HRRCA statement that passive techniques are much less expensive. The commenter supported the NAS findings that the effectiveness of these techniques in normal construction practice is uncertain.

EPA Response 7–6

Builders have reported costs as low as $100 to install radon resistant new construction features which is significantly less than the $350—$500 that was derived in EPA's cost-effectiveness analysis of the radon model standards. The cost of materials alone for the passive system will always be less than the cost for an active system which includes the cost of a fan. In many areas, the majority of the features for radon-resistant new construction are already required by code or are common building practice, such as an aggregate layer, ''poly'' sheeting, and sealing and other weatherization techniques. The only additional cost is associated with the vent stack consisting of PVC pipe and fittings. In those areas where gravel is not commonly used, builders can use a drain tile loop or other alternative less costly than gravel to facilitate communication under the slab. EPA estimates that the cost to mitigate an existing home ranges from $800 to $2,500 with an average cost of $1,200.

(d) Annual costs and benefits of MMM program implementation. Several concerns were raised regarding the costs and benefits associated with MMM program implementation. One commenter suggested that the MMM program description in the HRRCA provides essentially no guidance on the point from which additional risk reduction due to MMM will be measured.

EPA Response 7–7

The HRRCA was not intended to include a discussion and description of the criteria for EPA approval of State MMM programs. Rather, proposed criteria are presented in this proposed rule. EPA's proposed criteria do not entail a determination by the State of the level of indoor radon risk reduction that has already occurred (''baseline'') as the basis for determining how much more risk reduction needs to take place. Rather States, with public participation, are required to set goals that reflect State and local needs and concerns.

Another commenter states that EPA has underestimated the benefits of an MMM program. The HRRCA registers only the benefits gained in relation to water being treated to the MCL. However, according to EPA's figures, MMM benefits are expected to be much higher than those achieved by mitigating water alone.

EPA Response 7–8

EPA anticipates that MMM programs will result in sufficient risk reduction to achieve ''equal or greater'' risk reduction. A complete discussion on why MMM is expected to achieve equal or greater risk reduction is shown in Section VI.B of today's preamble. For the purposes of the HRRCA analyses, EPA made the conservative assumption that the level of risk reduction would at least be ''equal'' to that achieved by universal compliance with the MCL.

8. Other Key Comments

(a) Omission of non-transient non-community water systems (NTNCWSs). Eleven commenters criticized EPA's failure to include NTNCWSs in the HRRCA. Three commenters indicate that failure to include NTNCWSs grossly underestimates costs of radon mitigation. Another commenter also suggests that NTNCWSs should be included in the HRRCA, to provide a better picture of both costs and benefits. Two commenters would also like NTNCWSs included because impacts on these systems are likely to be high. Other commenters maintain that excluding NTNCWSs skews benefit-cost analyses in favor of regulation. Another commenter indicates that NTNCWSs, because of the type of wells and aquifers that they draw from, will be most affected by a radon rule.

EPA Response 8–1

Partly as a result of concerns raised by commenters, and partly as a result of its own preliminary analysis of exposure and risk, EPA is not proposing that NTNCWSs be covered by this rule. A more complete discussion of this issue